NPS-MA-95-009

NAVAL POSTGRADUATE SCHOOL
Monterey, California

R & D GTDS SST:
Code Flowcharts and Input

by

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1 September 1995 - 30 December 1995

Prepared for: Naval Postgraduate School
Monterey, CA 93943

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 30, 1995	Technical Report 1 Sep 1995 - 30 Dec 1995

4. TITLE AND SUBTITLE
R & D GTDS SST: Code Flowcharts and Input

5. FUNDING NUMBERS

6. AUTHOR(S)
Beny Neta and D. A. Danielson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER
NPS-MA-95-009

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this report are those of the authors and do not reflect the official policy or position of the Department of Defense or the United States Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This document describes the major capabilities of the Research and Development Goddard Trajectory Determination System (R&D GTDS) Code. Only the Ephemeris Generation and Differential Corrections are described in detail with several examples. This is a follow-on to our document collecting the mathematical algorithms used in R&D GTDS.

14. SUBJECT TERMS
major capabilities of the Research and Development Goddard Trajectory Determination System (R&D GTDS) Code

15. NUMBER OF PAGES
159

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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Acknowledgements

Dr. Steve Knowles of the Naval Space Command gave the initial impetus for this undertaking. Dr. Paul Cefola, Dr. Ron Proulx, and Mr. Wayne McClain were always helpful and supportive of our work. NAVSPACECOM (formerly NAVSPASUR) and the NPS Research Program provided the necessary financial support.

Chapter 1

Introduction

This document will describe part of the Research and Development Goddard Trajectory Determination System (R & D GTDS) Code concerning semianalytic satellite theory. The mathematical algorithms for this code are contained in Danielson, Sagovac, Neta and Early [1]. Here we collect information about the code and the input required to bridge the Fortran source code now running on a SUN sparc 10 workstation and the mathematical algorithms.

Leo Early [2] prepared linkage diagrams which will be used here. The source code was given to us by Dr. P. Cefola of Draper Laboratory and installed with the help of R. Metzinger. We will also use the User's Guide [3].

Chapter 2

Major Capabilities

R & D GTDS system in partitioned into the following programs:

i.	Ephemeris Generation (EPHEM) Program	(EP)
ii.	Differential Correction (DC) Program	(DC)
iii.	Early Orbit Determination (EARLYORB) Program	(EO)
iv.	Permanent File Report Generation (FILERPT) Program	(FR)
v.	Ephemeris Comparison (COMPARE) Program	(CM)
vi.	Filter (FILTER) Program	(FL)
vii.	Error Analysis (ANALYSIS) Program	(EA)
viii	Data Simulation (DATASIM) Program	(DS)
ix.	Data Management (DATAMGT) Program	(DM)

Note that the 2 letter code in parenthesis refers to the program name as abbreviated in the User's Guide [3] and the 2-8 letter code is the program name as required in the input control card (see later the discussion of the subroutine SETRUN).

The ephemeris generation (EPHEM) program propagates the object's state and state partial derivatives from prescribed initial conditions over a given time span. In order to meet varying precision and efficiency requirements, several orbital theories have been provided, ranging from a first order analytic theory to a high precision Cowell-type numerical integration. In this document, we only discuss the semianalytic satellite theory. The state transition matrix can also be generated, either by analytic approximation or by numerical integration of variational equations. Output is generated on a printer with the object's state (position and velocity) referenced to the indicated central body. The output can optionally include the state vectors related to specified noncentral bodies. Satellite ephemeris files can also be generated upon request.

The differential correction (DC) program estimates the values of a set of parameters (referred to as solved-for variables), in a mathematical model of a satellite motion. These parameters are determined so as to minimize (in a weighted least-square sense) the difference between computed and observed trajectory, while the solve-for variables are constrained to satisfy a-priori estimates to within a specified uncertainty. Both mean and covariance matrix are determined for the estimated parameters. Printer plots of observation residuals can be requested.

The early orbit determination (EARLYORB) program is designed to calculate an initial estimate of an Earth orbit when there is **no** a-priori estimate available to start a DC. This program uses several selected station observations (at least six) to rapidly approximate an initial estimate (starting vector) for the DC program.

The permanent file report generation (FILERPT) program generates reports describing the data and models existing in the R & D GTDS online data base and solar/lunar/planetary (SLP) ephemeris files. At the user's request, summary and/or complete reports can be obtained from each file. Information concerning observations, station positions, astrodynamics constants, potential fields, integration coefficients and other data files is available.

The ephemeris comparison (COMPARE) program compares two ephemerides which are input in the ORB1, EPHEM or ORBIT files. The comparison can be specified optionally over a particular arc or over the arc of overlap between the ephemerides. The radial, along-track and cross-track differenes are given in tabular form and printer plots may be produced upon request.

The filter (FILTER) program incorporates two sequential estimation algorithms, i.e. sequential Kalman filter and extended sequential Kalman filter, which process each observation to recursively update the state at each observation time.

The error analysis (ANALYSIS) program provides the capability to determine satellite state uncertainty about a given orbit as a function of epoch state uncertainty, observation data uncertainties and uncertainties in system parameters for a given station-dependent tracking schedule. This program provides for observation types modeled in the DC program.

The data simulation (DATASIM) program computes, at a given frequency, simulated observations for given sets of tracking stations and observation intervals.

The data management (DATAMGT) program is used to retrieve data from GTDS online database to create temporary working files to be used by other programs. This program operates as part of the program that will use the working files created.

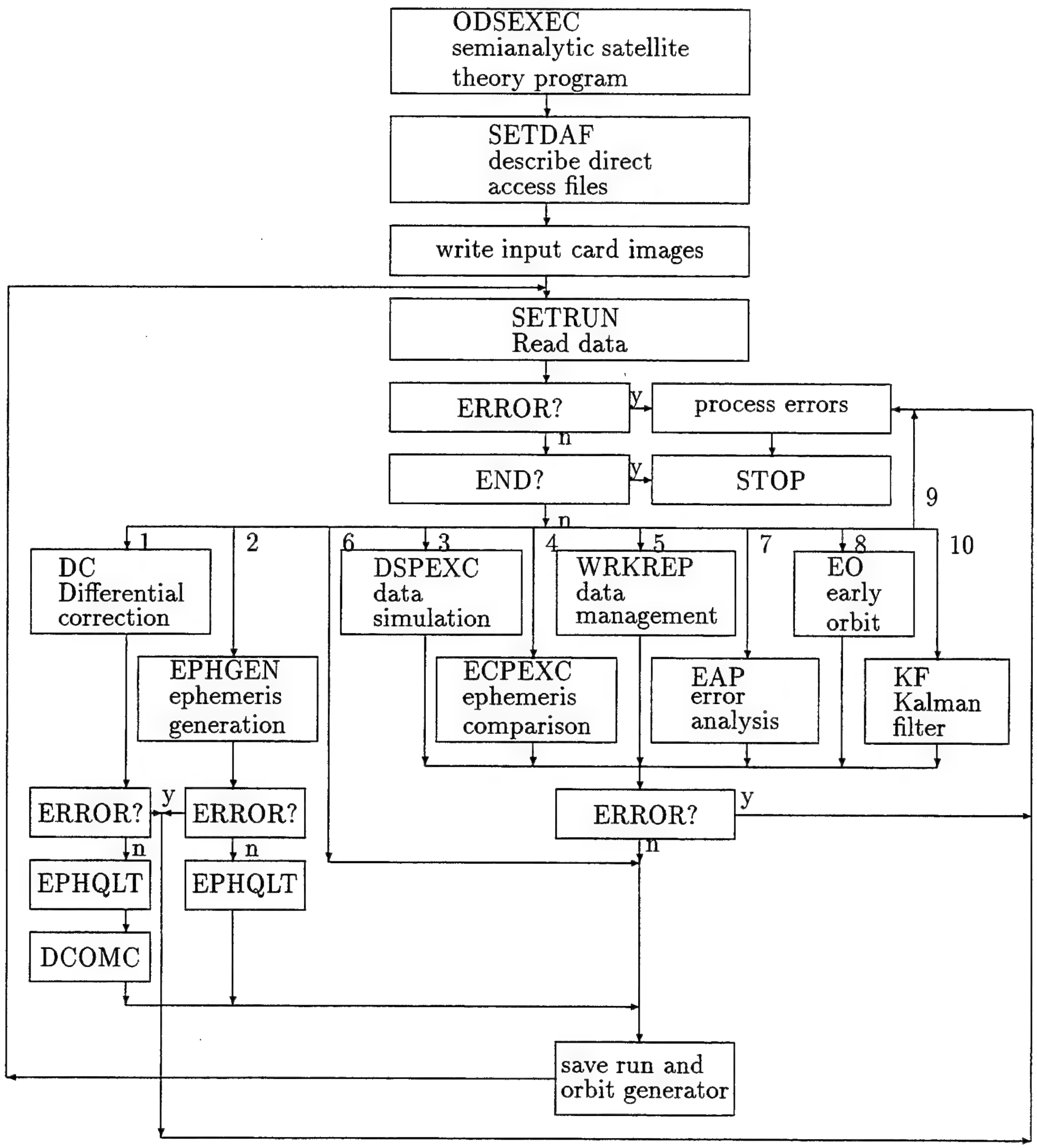
Chapter 3

ODSEXEC - SST Program

3.1 Flowchart

In this section we give a flow chart for the main program (ODSEXEC) using semianalytic satellite motion model. The program calls SETRUN to read the data cards and then passes control to one of 8 programs (based on a switch INDRUN resulting from the input card CONTROL). The switch as related to the subprogram name and the program name as given on the CONTROL card is given in the table.

INDRUN	Subprogram name	Program name on CONTROL card
1	DC	DC (Differential Correction)
2	EPHGEN	EPHEM (Ephemeris Generation)
3	DSPEXC	DATASIM (Data Simulation)
4	ECPEXC	COMPARE (Ephemeris Compare)
5	WRKREP	DATAMGT (Data Management)
6		FILERPT (File Report)
7	EAP	ANALYSIS (Error Analysis)
8	EO	EARLYORB (Early Orbit)
9	not used	
10	KF	FILTER (Kalman Filter)


ODSEXEC
semianalytic satellite
theory program
SETDAF
describe direct
access files
write input card images
SETRUN
Read data
ERROR?
y
process errors
n
END?
y
STOP
9
n
1
2
6
3
4
5
7
8
10
DC
Differential
correction
DSPEXC
data
simulation
WRKREP
data
management
EO
early
orbit
EPHGEN
ephemeris
generation
ECPEXC
ephemeris
comparison
EAP
error
analysis
KF
Kalman
filter
ERROR?
y
ERROR?
ERROR?
y
n
n
n
EPHQLT
EPHQLT
DCOMC
save run and
orbit generator

Since this document is concerned only with the semianalytic model, we will only discuss the following programs: DC and EPHEM . Before we go to these programs we describe the subroutine SETRUN which reads the input deck for SST.

3.2 Subroutine SETRUN

This subroutine reads and processes the control card which has the following format:

Columns	Format	Contents/Description	
1-8	A8	CONTROL	
11-18	A8	DC	- the program name to be run
		EPHEM	
		DATASIM	
		COMPARE	
		DATAMGT	
		FILERPT	
		ANALYSIS	
		EARLY ORB	
		FILTER	
31-38	A8	blank	- print all card images
		NO-PRINT	- print all those in errors
41-48	A8	INPUT	- pass initial values from previous run
		OUTPUT	- pass final values from previous run
51-58	A8	blank (default)	- Do not restore COMMON block values to initial values
		otherwise	- restore
61-68	A8	satellite name	
69-70	I2	blank	
72-78	I7	number	satellite identification (right justify)

Notes: 1. all input is left justified
2. all other columns are blank
3. Control card must be the first card in each deck

Next, the program reads and processes the mandatory cards (depending on the program as given in the control card columns 11-18). Then, the subroutine calls the appropriate subroutines to process any optional card subdecks.

In the next sections we discuss the programs EPHEM and DC and we give a list of mandatory and optional cards for each.

Chapter 4

Ephemeris Generation (EPHEM) Program

The primary function of the Ephemeris Generation Program is to compute a time history of a spacecraft trajectory from a given set of initial conditions. Typical output is in the form of a printer file of Cartesian coordinates and Keplerian orbital elements at various times during the flight. One can output a satellite ephemeris file for use in the Data Simulation (DATASIM), Error Analysis (ANALYSIS), and Ephemeris Comparison (COMPARE) programs. In addition, the EPHEM program can be used to advance elements from the given epoch to another and to store the new elements in a file or a COMMON block for use in a subsequent run. Together with a DC program, one can update the catalog of objects orbiting the Earth.

The input data specified for an EPHEM run are:

i. Initial elements and epoch
ii. Orbit generator selection
iii. Conversion of osculating-to-mean elements
iv. Selection of numerical integration method
v. Output file creation and retrieval
vi. Force model options
vii. Partial derivatives

4.1 EPHEM Required Keywords

The mandatory keyword cards specify initial conditions, orbit generator type and key options, principal integration parameters, and output parameters. If no other input is supplied, the program will operate with default values for force model and optional integration parameters. We now list all keywords required.

required keywords, EPHEM

1.	CONTROL	- was already discussed
2.	ELEMENT1	- sets coordinate system, reference central body, and first 3 components of initial state
3.	ELEMENT2	- sets the second 3 components of initial state
4.	EPOCH	- specifies the epoch of state
5.	ORBTYPE	- sets orbit generator type and principal integration parameters
6.	OUTPUT	- sets end time and print interval of program execution
7.	FIN	- indicates the end of program deck

Notes: 1. If any data management functions are required, these mandatory keyword must be followed by the DMOPT subdeck keyword, optional data management keywords, and the keyword END.

2. If orbit generation options are required, the subdeck keyword OGOPT with the proper optional keywords and an END keyword may be included.

3. This program input deck can be followed by another program input deck(s) for another EPHEM or other programs.

4.1.1 ELEMENT1, ELEMENT2, ELEMENT3, EPOCH cards

ELEMENT1

Columns	Format		Contents/Description
1-8	A8		ELEMENT1
9-11	I 3		Coordinate system orientation
		1	mean Earth equator and equinox of 1950 (osculating)
		2	true of reference, Earth equator and equinox (osculating)
		3	true of epoch, Earth equator and equinox (treated as 2) (osculating)
		4	mean ecliptic and equinox of 1950 (for Cowell integrators only) (mean)
		5	true of epoch, ecliptic and equinox (for Cowell integrators only) (osculating)
		6	NORAD true of date (for Cowell integrators only) (mean)
		7	not used
		8	NORAD true of reference (for GP orbit generators)
		9	mean Earth equator and equinox of J2000. (Not operational)
		10	Earth centered, Earth fixed (Not operational)
12-14	I 3		Coordinate system type
		1	Cartesian
		2	Keplerian
		3	spherical
		4	mean Keplerian (used with Brouwer, Brouwer-Lyddane, Brouwer-Gordon and Vinti analytic propagators)
		5	DODS flight parameters
		6	Averaged Keplerian (used with averaged VOP integrator)
		7	Keplerian selenographic (body-fixed, moon centered). Next parameter muts be 2.
		8	Averaged equinoctial (used with averaged VOP integrator)
		9	Equinoctial
		10	NORAD SGP elements (GTDS format)

		11	NORAD GP4/DP4 elements (GTDS format)
		12	NORAD HANDE (GTDS format)
		13	NORAD SALT (GTDS format)
		14	NORAD SGP elements (SPADOC format)
		15	NORAD GP4/DP4 elements (SPADOC format)
		16	NORAD HANDE elements (SPADOC format)
		17	NORAD SALT elements (SPADOC format)
		18	NORAD SGP elements (from NORAD historical data system)
15-17	I 3		Input reference central body of initial state.
		1	Earth
		2	moon (Must choose this if 7 in previous field)
		3	Sun
		4	Mars
		5	Jupiter
		6	Saturn
		7	Uranus
		8	Neptune
		9	Pluto
		10	Mercury
		11	Venus
18-38	G21.14		x component of position (km) (Cartesian)
			semimajor axis (km) (Keplerian, Equinoctial)
			Right ascension (deg) (spherical)
			East longitude (deg) (DODS)
			mean motion (revs/day) (SPADOC)
39-59	G21.14		y component of position (km) (Cartesian)
			eccentricity (Keplerian, SPADOC)
			declination (deg) (Spherical)
			geodetic latitude (deg) (DODS)
		h	(dimensionless) (Equinoctial)

60-80	G21.14		z component of position (km) (Cartesian)
			Inclination (deg) (Keplerian, SPADOC)
			Vertical flight path angle (deg) (Spherical)
			horizontal flight path angle (deg) (DODS)
		k	(dimensionless) (Equinoctial)

<u>ELEMENT2</u>

Columns	Format		Contents/Description
1-8	A8		ELEMENT2
9-17			blank
18-38	G21.14		x component of velocity ($\frac{km}{sec}$) (Cartesian)
			longitude of ascending node (Ω) (deg) (Keplerian, SPADOC)
			azimuth (inertial) (spherical, DODS)
		p	(dimensionless) (Equinoctial)
39-59	G21.14		y component of velocity (Cartesian)
			argument of perigee (ω) (deg) (Keplerian, SPADOC)
			radius (km) (Spherical, DODS)
		q	(dimensionless) (Equinoctial)
60-80	G21.14		z component of velocity ($\frac{km}{sec}$) (Cartesian)
			mean anomaly (M) (Keplerian, SPADOC)
			velocity ($\frac{km}{sec}$) (Spherical, DODS)
		λ	(deg) (Equinoctial)

This elemet card is required only for NORAD GP theory.

ELEMENT3

Columns	Format	Contents/Description
1-8	A8	ELEMENT3
9-17		blank
18-38	G21.14	$\dot{n}_0/2$ in rev/day^2 for SGP, HANDE
39-59	G21.14	$\ddot{n}_0/6$ in rev/day^3 for SGP, HANDE
60-80	G21.14	B^* in $EarthRadii^{-1}$ for GP4 B in m^2/kg for HANDE

EPOCH

Columns	Format	Contents/Description
1-8	A8	EPOCH (left justified)
9-17		blank
18-38	G21.14	yymmdd.0 (year, month, day of epoch)[1]
39-59	G21.14	hhmmss.ssss (hours, min., sec. of epoch)
60-80	G21.14	Automatic epoch advance (for DC only) yymmddhhmmss.ssss time about which to perform differential corrections. The default - no epoch advance desired.

[1]This date will be the default for the reference date when integrating in the true of reference system (second keyword in ELEMENT1) unless overriden by the keyword TIMES.

4.1.2 ORBTYPE, OUTPUT, FIN cards

ORBTYPE

Columns	Format	Contents/Description
1-8	A8	ORBTYPE (left justified)
9-11	I 3	Orbit generator type (The rest of the card is for SST-Code 5) 1 - Time regularized Cowell (See TIMREG Card) 2 - Cowell (default) 3 - Brouwer 4 - Brouwer - Lyddane 5 - SST (Averaged VOP) 6 - Pregenerated orbit file 7 - Osculating VOP 8 - not used 9 - Chebyshev series integrator 10 - Runge - Kutta - Fehlberg numerical integrator (for FILTER program only) 11 - Brouwer - Gordon 12 - Vinti 13 - SGP 14 - GP4/DP4 (automatic selection) 15 - DP4 16 - HANDE (7 parameter input) 17 - HANDE (18 parameter input) 18 - SALT 19 - PPT2 (not operational yet)
12-14	I 3	integration step mode 1 (default) fixed step 2 regular variable step 4 halving - doubling tolerance for the atuomatic variable step options 2, 4 are specified by TOLER, UPPBOUND, LOWBOUND and NOMBOUND keywords.

15-17	I3	Coordinate system orientation 1 - (default) mean equator and equinox of 1950 2 - true of reference (precession and nutation are ignored in coordinate transformations during the integration. Thus, this choice is desirable **only** when the integration span is short and the span is in proximity to the reference date.
18-38	G21.14	Integration stepsize in seconds (default 86400)
39-59	G21.14	Integration method options blank - multistep 1 - Runge Kutta Runge Kutta with fixed stepsize must be employed if short periodics are on. The multistep with fixed stepsize may be employed if short periodics are off. The multistep method is recommended for long integration (several months or years).
60 - 80	G21.14	Type of VOP (default = 12)

OUTPUT

Columns	Format	Contents/Description
1-8	A8	OUTPUT (left justified)
9-11	I3	Output coordinate system orientation 1 - mean Earth equator and equinox of 1950. 2 - true of reference (inertial) 3 - true of reference or date (body-fixed) 4 - mean ecliptic and equinox of 1950. 5 - true of date, ecliptic and equinox 6 - NORAD true equator and mean equinox of output date 7 - not used 8 - NORAD true equator and mean equinox of epoch. (OUTCOORD to override.)
12-14	I 3	Output reference system type 1 - Cartesian (position, velocity, latitude, height) 2 - Cartesian, Keplerian and spherical (default) 3 - Cartesian, Keplerian, spherical and mean (elements associated with Brouwer - Lyddane). If VOP integrator is used one get osculating instead of mean elements. If column 14 is as above and column 13 is 9 then one **also** take L-1 rotating system. If column 14 is as above and column 13 is 1 - print at ascending nodes 2 - print at descending nodes 3 - print at both. (OUTTYPE to override)
15-17	I 3	Output reference body 1 - Earth 2 - Sun 4 - Moon 8 - target body (defined as central body of the final flight section (OUTBODY to override)

18-38	G21-14	yymmdd - year, month, day of end of print arc
39-59	G21.14	hhmmss.ssss - hours, min., sec. of end of print arc (the start time is epoch by default or use the keyword TIMES.)
60-80	G21.14	output print interval in seconds **or** Nodal print frequency if we need to print at every N^{th} point (see remark for column 13 above)

FIN

Columns	Description
1-3	FIN

4.1.3 Examples

In this subsection we give several examples of the mandatory cards in EPHEM runs.

```
CONTROL   EPHEM                                          LNDSAT-4   8207201
EPOCH               820223.0         0.0
ELEMENT1  3  6  1   7077.787         0.011542            98.250452
ELEMENT2            158.15349        89.4                312.90205
OUTPUT    1  2  1   820224.0         0.0                 43200.0
ORBTYPE   5  1  1   43200.0          1.0
FIN
```

The CONTROL card tells us that this is an EPHEM run. The card images will be printed (blank in columns 31-38). The COMMON blocks will not be restored (columns 51-58 are blank). The satellite name is given in columns 61-72. The satellite is identified by the 7 digit number (RIGHT justified) 8207201 given in columns 72-78.

The EPOCH card tells us the date of epoch is 23 February 1982 and the time is 00:00:00.

The ELEMENT1,2 cards give the following information: This is true of epoch, Earth equator and equinox orientation (3). The coorinate system is averaged Keplerian (6) and

Earth is the central body of initial state (1). The semi major axis is 7077.787, the eccentricity is .011542 and the inclination is 98.250452. The second card gives the longitude of ascending nodes = 158.15349, the argument of perigee = 89.4, and the mean anomaly = 312.90205.

The OUTPUT card tells us that the output coordinate system is mean Earth equator and equinox of 1950 (1), the output reference system type is Cartesian, Keplerian and Spherical (2), and the output reference body is Earth (1). February 24 1982 is the end of the print arc and the time is 00:00:00. The output print interval in seconds is 43200 (12 hours).

The ORBTYPE card tells us that we are using semianalytic satellite theory (5), with fixed integration step (1) and coordinate system orientation is mean equator and equinox of 1950 (1). The integration stepsize in seconds is 43200 and the integration method is Runge Kutta (1). The last card, FIN, is the end of the deck.

Another example for a second EPHEM run (must be preceded by an EPHEM deck) is given in the following

```
CONTROL   EPHEM                          OUTPUT              LNDSAT-4   8207201
OUTPUT    1  2  1  820302.0             0.0                 86400.0
ORBTYPE   2  1  1  60.0
FIN
```

Notice that ELEMENT1, ELEMENT2 and EPOCH cards are not given. This is possible only if the CONTROL card gives the parameter OUTPUT in columns 41-48, meaning that this is the same object discussed in the previous EPHEM deck. Note also that the identification of the object in the two examples is the same.

The OUTPUT cards has the same first 3 numbers. The end of the print arc is now March 2, 1982 at time 00:00:00 and the print interval is twice as large (86400 seconds).

The ORBTYPE card specifies Cowell orbit genearator (2), with the same fixed integration step (1) and the same coordinate system orientation. The integration step size now is 60 seconds.

The last card is FIN, final card of the deck.

4.2 Optional Keywords

See Table for all applicable optional keywords for the DCOPT, DMOPT and OGOPT subdecks

OGOPT	card
DCOPT	card
DMOPT	card

4.2.1 DCOPT, DMOPT, OGOPT, END

These three cards are used to identify a subdeck. Each subdeck will allow certain cards to be included. A list will be given here.

DCOPT

Columns	Format	Contents
1-5	A5	DCOPT

This subdeck is used with the following programs: DC, FILTER, EARLYORB, DATASIM and ANALYSIS. This subdeck contains any of, the following cards (we give only those required with DC) and terminates with END

A	EDIT	MODDC	SSELEM2
ACCREJ	ELLMODEL	OBSCORR	SSEPOCH
ATMOSH	EXECCOV1	PASSTIME	SSOPT
BATCHTYP	EXECCOV2	PRINTOUT	TRACELV
CONSIDER	GPSANGLE	PSA	TRNDLY
CONVERG	GPSBIAS	SAVE	USERBIAS
CWEIGHT	INTEROUT	SSCOVAR	1 thru 9
D	ISEEHALO	SSELEM1	

DMOPT

Columns	Format	Contents
1-5	A5	DMOPT

This subdeck is used with the following programs: EPHEM, DC, FILTER, EARLYORB, DATASIM, ANALYSIS and DATAMGT.

It must be the first subdeck. It contains any of the following cards (we give only those required with EPHEM and/or DC).

A	OBSDEV	SLPFILE	WORKINT
ACCREJ	RELAYID	SORINPUT	WORKIONO
CHWT	SELOUT	WORKATM	WORKMAN
D	SLPBODY	WORKCON	WORKOBS
LNDPAR	SLPCOORD	WORKELS	WORKSECT
MIXPAIR	SLPDEG	WORKGEO	1 thru 2

OGOPT

Columns	Format	Contents
1-5	A5	OGOPT

This subdeck is used with the following programs: EPHEM, DC, FILTER, EARLYORB, DATASIM, and ANALYSIS. It contains any of the following:

APOFOCAL	IMPULSE	RAPRIME	SPSRP
ATMOSDEN	INTEG	RATIME	SPTESSLC
ATTANG1	INTEROUT	RCACB	SPZONALS
ATTANG2	INTMODE	RCANCB	SSTAPGFL
ATTANG3	LGEM	RESNM	SSTESTFL
ATTPAR	LIFETIME	RESONPRD	SSTESTOU
AUTOFORC	LOWBOUND	RESTART	SSTSPPGF
AVERAGE	MANMASS	ROLLVAR	STATEPAR
AVRHARM	MANTIME	RTASCVAR	STATETAB
AVRTHIRD	MAXDEGEQ	SCPARAM	STEPSIZE
(AVRTRUNC)	MAXDEGVE	SCPARAM2	THRSTCOF
BDROTATE	MAXORDEQ	SHELLRAD	THRSTPAR
BODYRAD	MAXORDVE	SNM	THRSTVAR
CBODY	MAXSECT	SOLRAD	THRUST
CNM	MEANEL	SOLRDPAR	TIMES
COVRNC	NCBODY	SPDRAG	TIMREG
DECLVAR	NOMBOUND	SPGRVFRC	TIMREGDV
DISTCB	NPQPAR	SPHERE	TITLE
DISTNCB	OUTBODY	SPHINF	TOF
DRAG	OUTCOORD	SPINTCOF	TOLER
DRAGPAR	OUTOPT	SPINTPOS	TWOBODY
EPHQLRCT	OUTPART	SPJ2MDLY	UPPBOUND
FLATCOEF	OUTTYPE	SPLUNARA	
GMCON	PICBIAS	SPMDAILY	
GMPAR	POLAR	SPNUMGRV	
HARMONIC	POTFIELD	SPOUTPUT	
HSTPLOT		SPSHPER	
HSTSCALE		SPSOLARA	

<u>END</u>

Columns	Format	Contents
1-3	A3	END

4.3 Initial Elements and Epoch

There are five methods for inputting initial elements and epoch into an EPHEM program. These are:

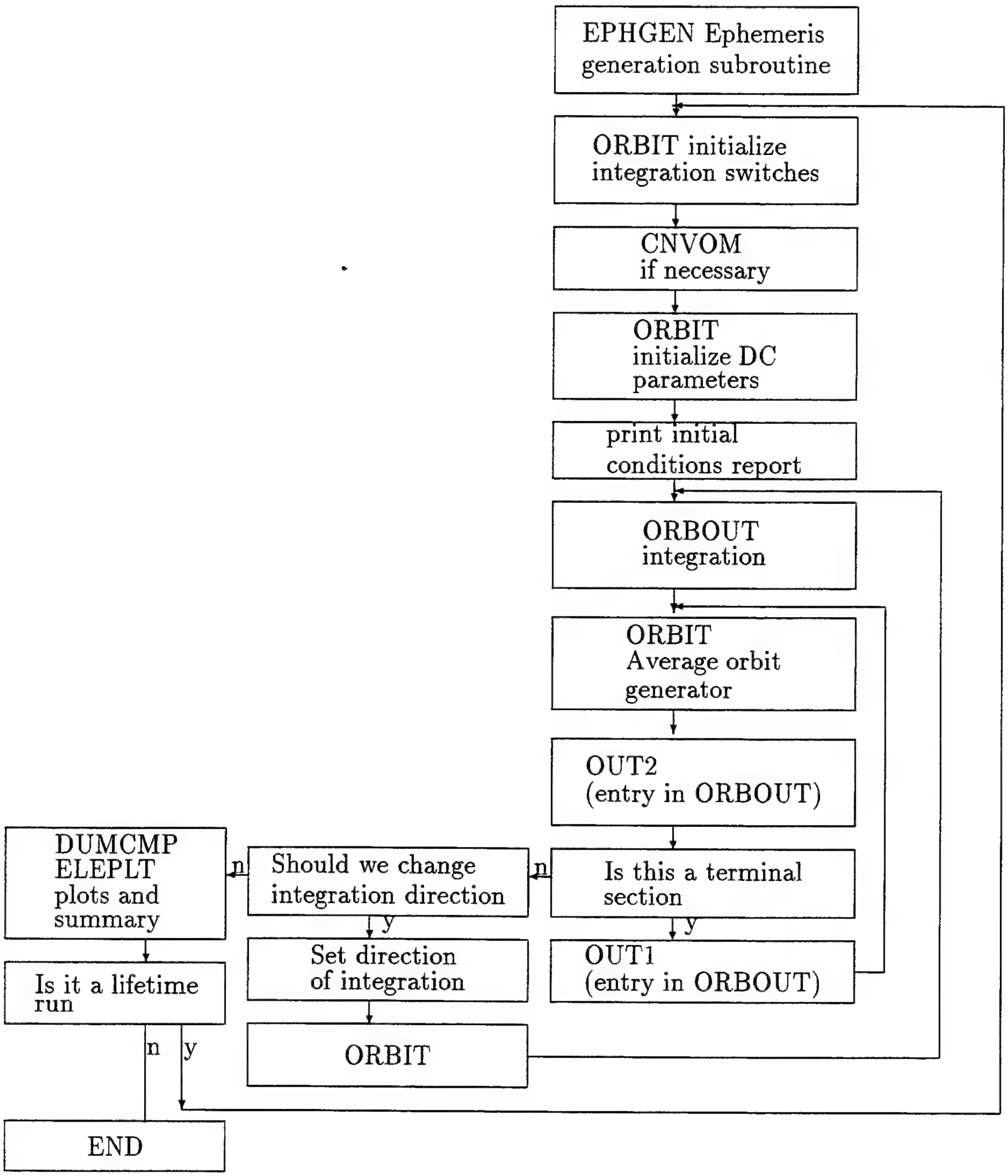
- "Punched - card" input (ELEMENT1, ELEMENT2, EPOCH cards)
- 24 hour hold elements file (see WORKELS card)
- GTDS permanent elements file (see WORKELS card)
- DODS permanent elements file (see WORKELS card)
- Block COMMON from a previous step (see columns 51-58 of CONTROL card)

4.3.1 WORKELS

This card is part of DMOPT subdeck. In this case one does not use ELEMENT1, ELEMENT2, and EPOCH cards.

Columns	Format	Description/Contents
1-8	A8	WORKELS (left justified)
9-11	I 3	Elements source 0 - ELEMENT1 and ELEMENT2 cards 1 - GTDS permanent elements file 2 - 24- hour hold elements file 3 - DODS permanent elements file (Columns 18-38 determines the type of elements search made. When the element set number is provided, this number will be used to retrieve the elements. If this field is blank, the elements set closest to Epoch is retrieved.)
12-14	I 3	Write elements to 24-hour hold elements file at the end of run: 1 - yes 2 - no (default)
15-17	I 3	Write elements to permanent elements file at the end of run: 1 - yes 2 - no (default)
18-38	G21.14	Elements set number
39-59	G21.14	Epoch time (yymmdd.0 - for source 3 only)
60-80	G21.14	Epoch time (hhmmss.ssss - for source 3 only) **or** GTDS permanent elements file password.

4.4 Flowchart



4.5 Orbit Generation Selection

The orbit generator is selected in ORBTYPE card (see 3.3.1.2). The time-regularized Cowell, Cowell, Variation of parameters, Runge-Kutta - Fehlberg and Chebyshev series orbit generators are all high-precision (types 1, 2, 5, 7, 9, 10). The Brouwer, Brouwer -Lyddane, Brouwer-Gordon and Vinti (types 3, 4, 11, 12) as well as the NORAD (SGP, GP4/DP4, DP4, HANDE, and PPT2, types 13-17, 19) are analytical methods. Note that PPT2 is not operational yet. The time regularization constants can be modified by means of the TIMREG card. Options for the numerically averaged orbit generators can be specified by the AVERAGE card. The Runge-Kutta Fehlberg (type 10) orbit generator is for the FILTER program only.

4.5.1 TIMREG, TIMES

These cards are part of OGOPT subdeck. TIMREG is used to set section-dependent time regularization constant of the satellite radius and TIMES is used to set the run reference date and the EPHEM print start time.

TIMREG

Columns	Format	Contents/Description
1-8	A8	TIMREG
9-11	I 3	flight section I
12-14	I 3	flight section J
15-17	I 3	flight section K
18-38	G21.14	Time regularization exponent for section I
39-59	G21.14	Time regularization exponent for section J
60-80	G21.14	Time regularization exponent for section K

The exponent n for each section ranges from 1 (independent variable is the eccentric anomaly) to 2 (true anomaly). The default value is 1.5.

TIMES

Columns	Format	Contents/Description
1-8	A8	TIMES
9-11	I 3	blank
12-14	I 3	blank
15-17	I 3	blank
18-38	G21.14	reference date (yymmdd.0) for true reference system default is epoch
39-59	G21.14	start time of print arc (yymmdd.0) default is epoch
60-80	G21.14	start time of print arc (hhmmss.ssss)

4.5.2 AVERAGE

This cards is part of OGOPT subdeck.

Columns	Format	Contents/Description
1-8	A8	AVERAGE
9-11	I 3	quadrature control option for continuous perturbation: 1 - (default) - quadrature is chosen automatically, using the order on this card initially. 2 - quadrature order is given (12, 16, 20, 24, 32, 40 or 48)
12-14	I 3	quadrature control option for drag (default)
15-17	I 3	quadrature control option for solar radiation pressure (default = 1)
18-38	G21.14	quadrature order for continuous perturbations (12, 16, 20, 24, 32, 40, 48) default = 12
39-59	G21.14	same for drag
60-80	G21.14	same for solar radiation pressure

4.6 Conversion of Osculating-to-Mean Elements

If a numerically averaged orbit generator has been requested via the ORBTYPE card and osculating elements have been given (e.g. via ELEMENT1 card), a numerical osculating-to mean element conversion is performed. The conversion requires the generation of an ORBIT file. Using the default options, this file is created using the time-regularized Cowell orbit generator with a stepsize of 150 steps per revolution, and the conversion is performed by averaging osculating elements over one satellite revolution. The orbit generator, stepsize, and number of revolutions to be averaged over, can be modified by MEANEL card.

If either of the Brouwer analytical orbit generators has been requested by ORBTYPE card and osculating elements have been input, and iterative osculating-to-mean element conversion via the analytic theory is performed.

4.6.1 MEANEL

This card is part of OGOPT subdeck and it is used to set options for the numerical osculating-to-mean conversion for VOP orbit generator.

Columns	Format	Description/Contents
1-8	A8	MEANEL
9-11	I 3	Orbit generator used to generate the ORBIT file 0 - same as previous 1 - (default) time regularized Cowell 2 - Cowell
12-14	I 3	Number of satellite orbits averaged over 0 - the number is as before $N > 0$, N orbits (default = 1)
18-38	G21.14	For time-regularized Cowell: Number of integration steps per revolution (default = 150) For Cowell: Integration stepsize in seconds (default = 24)

4.7 Selection of Numerical Integration Method

The default numerical integrator is the 12^{th} order Cowell multistep with fixed stepsize. Three variable stepsize options are available:

- halving-doubling
- regular variable step
- variable stepsize shell mode

These options as well as the stepsize, if fixed, are specified on ORBTYPE card. For variable stepsize the default initial step is 24 seconds. For multisection flights, this information is given on INTMODE, TIMREGDV or STEPSIZE cards. The tolerances for variable stepsize can be modified on TOLER card in OGOPT subdeck. For multisection flights, this is given on LOWBOUND, NOMBOUND, and UPPBOUND cards.

A single step Runge-Kutta integrator is also available and can be specified on INTEG card in OGOPT subdeck.

For multistep integrators, one can have either multistep or single step starting integrator. The multistep default can be modified on RESTART card. The order of the multistep integrator can be modified on WORKINT card in DMOPT subdeck.

The starter stepsize control parameters used with the variable stepsize shell mode method can be modified on SHELLRAD card.

4.7.1 INTEG

This card is part of OGOPT deck to set numerical integration parameters.

Columns	Format	Description/Contents
1-8	A8	INTEG
9-11	I 3	Numerical integrator 1 - single point off-grid 2 - Second sum Cowell (default) 3 - Adams 4 - Runge Kutta
12-14	I 3	Cowell integration order for the equations of motion (default = 12)
15-17	I 3	Cowell integration order for the variational equations (default = 8)

4.7.2 INTMODE

This card is part of OGOPT deck and used to set integration stepsize control mode. The possible modes are:

1 - (default) fixed step
2 - regular variable step
3 - shells
4 - halving-doubling

Columns	Format	Description/Contents
1-8	A8	INTMODE
9-11	I 3	Flight section I
12-14	I 3	Flight section J
15-17	I 3	Flight section K
18-38	G21.14	Integration step mode for section I
39-59	G21.14	Integration step mode for section J
60-80	G21.14	Integration step mode for section K

4.7.3 LOWBOUND/NOMBOUND/UPPBOUND

These card are part of OGOPT deck and used for setting stepsize control lower/nominal/upper bound on truncation error.

Columns	Format	Description/Contents
1-8	A8	LOWBOUND
9-11	I 3	Flight section I
12-14	I 3	Flight section J
15-17	I 3	Flight section K
18-38	G21.14	lower bound for section I if positive
39-59	G21.14	lower bound for section J if positive
60-80	G21.14	lower bound for section K if positive

The lower error bound initial value for all 10 sections can optionally be set to the same value given in TOLER card.

The cards NOMBOUND and UPPBOUND are identical to the above (except of course columns 1-8).

4.7.4 RESTART, STEPSIZE, TIMREGDV

These cards are used to set the integration starter option (either Runge-Kutta or Multistep), to set the integration stepsize, and the regularization stepsize constant.

Columns	Format	Description/Contents
1-8	A8	RESTART
9-11	I 3	Flight section I
12-14	I 3	Flight section J
15-17	I 3	Flight section K
18-38	G21.14	Restart option for section I
39-59	G21.14	Restart option for section J
60-80	G21.14	Restart option for section K

Note the possible options are:

1 - Multistep (default)
2 - Runge Kutta

Columns	Format	Description/Contents
1-8	A8	STEPSIZE
9-11	I 3	Flight section I
12-14	I 3	Flight section J
15-17	I 3	Flight section K
18-38	G21.14	stepsize in seconds for section I
39-59	G21.14	stepsize in seconds for section J
60-80	G21.14	stepsize in seconds for section K

Columns	Format	Description/Contents
1-8	A8	TIMREGDV
9-11	I 3	Flight section I
12-14	I 3	Flight section J
15-17	I 3	Flight section K
18-38	G21.14	Time regularization stepsize constant for section I
39-59	G21.14	Time regularization stepsize in seconds for section J
60-80	G21.14	Time regularization stepsize in seconds for section K

The stepsize is then: Period/stepsize constant given here.

4.7.5 TOLER

This card is part of OGOPT subdeck and it is used to set integration tolerances for all flight sections.

Columns	Format	Description/Contents
1-8	A8	TOLER
9-11	I 3	tolerance index I
12-14	I 3	tolerance index J
15-17	I 3	tolerance index K
18-38	G21.14	Tolerance assoicated with index I
39-59	G21.14	Tolerance assoicated with index J
60-80	G21.14	Tolerance assoicated with index K

Tolerance index	description	default
1	Upper truncation error bound	.25 D-7
2	lower truncation error bound	.25 D-13
3	nominal truncation error bound	.25 D-10
4	Corrector tolerance for Cowell single step integrator	.5 D-8
5	Corrector tolerance for equations of motion starter	.1 D-12
6	Corrector tolerance for variational equations starter	.1 D-12
7	Increase factor for stepsize computation	.2
8	Minimum stepsize	5. sec
11	max. # of corrector iterations for Cowell single step	3
12	same for Cowell multi-step starter	15
13	Max. # of stepsize restarts for multistep starter	5

Note: The upper, lower and nominal trucation error bounds maybe overridden by the cards UPPBOUND, LOWBOUND, NOMBOUND.

4.7.6 SHELLRAD

This card is part of OGOPT subdeck and is used to set the radial distance and stepsize for the integrator when using the shell mode.

Columns	Format	Description/Contents
1-8	A8	SHELLRAD
9-11	I 3	Flight section for radial distance and integration stepsize
12-14	I 3	shell set number (max. of 15)
18-38	G21.14	radial distance in km for specified section and shell
39-59	G21.14	integration stepsize in seconds for that section and shell

Note:
The cards INTEG, ORBTYPE and/or INTMODE must be used to set the proper options.

4.7.7 WORKINT

This card is part of DMOPT subdeck and it is used to build a working file of integration coefficients.

Columns	Format	Description/Contents
1-8	A8	WORKINT
9-11	I 3	Degree of integration for equations of motion: range = 4 to 19 default = 12
12-14	I 3	Degree of integration for variational equations (same range and default)

4.8 Output File Creation and Retrieval

The ORBIT, EPHEM, and ORB1 files are satellite ephemeris files and can be requested in OUTOPT Card. ORBIT file can be generated **only** via a Cowell or time-regularized Cowell integrators. Partial derivatives may be included in the file.

The EPHEM program can be used to retrieve and print the satellite state and partial derivatives from an ORBIT file by using ORBTYPE card.

4.8.1 OUTOPT

Columns	Format		Description/Contents
1-8	A8		OUTOPT
9-11	I 3		Type of ephermeris file to generate:
		0	ORBIT file
		1	ORB1 file
		2	ORBIT **and** ORB1 files
		3	EPHEM file (Earth - centered true of date)
		4	ORBIT **and** EPHEM files
			20 - 24 same as 0-4 but to secondary unit
12-14	I 3		For ORBIT file only
		1	include partial derivatives
		2	(default) do not include partial derivatives
			For EPHEM files
			central body indicator (see ELEMENT1 columns 15 -17)
15-17	I 3		For ORBIT files
		0	sequential
		>0	direct access
			For EPHEM files
		1	1950
		2	true of date
18-38	G21.14		start time of arc (yymmddhhmmss.ssss)
39-59	G21.14		End time of arc (yymmddhhmmss.ssss)
60-80	G21.14		Output interval for ORB1 or EPHEM files (default - 60 sec)

Notes:
The ORBIT file will be referenced to the same central body and coordinate system as the integrator.

The secondary unit is used only for immediate COMPARE program.

Primary Unit	Secondary	File
19	86	ORBIT With partials
20	88	ORBIT without partials
21	82	ORBIT tape with partials
22	84	ORBIT tape without partials
24	81, 83, 85, 87	ORB1 or EPHEM

Note: In stacked cases when multiple EPHEM files are generated, the file number is circularly updated with each case starting with unit 24, then 31, 83, 85 and 87 unless a secondary unit is used first. If 81 is first then 24 follows 87.

4.8.2 OUTCOORD, OUTBODY, OUTTYPE

In this subsection, we discuss three cards of OGOPT subdeck used to modify output. The first card, OUTCOORD is used to set the output coordinate system orientation for each flight section. The second card, OUTBODY, is used to set additional output reference bodies for each flight section, and the last card, OUTTYPE, is used to set printer output reference system for each flight section.

Columns	Format		Description/Contents
1-8	A8		OUTCOORD
9-11	I 3		Flight section I
12-14	I 3		Flight section J
15-17	I 3		Flight section K
18-38	G21.14		Indicator for output coordinate system orientation for section I
		1	1950 body centered
		2	Body cenetered true of date (if integrating in 1950 system, otherwise true of reference)
		3	Body fixed true of date (if integrating in 1950 system, otherwise true of reference)
39-59	G21.14		Indicator for output coordinate system orientation for section J
60-80	G21.14		Indicator for output coordinate system orientation for section K

Note: Maximum 10 flight sections.

Columns	Format		Description/Contents
1-8	A8		OUTBODY
9-11	I 3		Flight section I
12-14	I 3		Flight section J
15-17	I 3		Flight section K
18-38	G21.14		Indicator for refernce bodies for section I
		1	geocentric output requested
		2	heliocentric output requested
		4	selenocentric output requested
		8	target body (central body of final section) output requested
			other possibilities by summing indicators
39-59	G21.14		Indicator for refernce bodies for section J
60-80	G21.14		Indicator for refernce bodies for section K

Note: Output with respect to integration central body is always printed.

Columns	Format		Description/Contents
1-8	A8		OUTTYPE
9-11	I 3		Flight section I
12-14	I 3		Flight section J
15-17	I 3		Flight section K
18-38	G21.14		Output coordinate system type for section I
		1	cartesian
		2	cartesian, Keplerian and spherical (default)
39-59	G21.14		Output coordinate system type for section J
60-80	G21.14		Output coordinate system type for section K

Note: Maximum 10 flight sections.

4.9 Force Model Options

The default force model includes one section with Earth as the central body and the Sun, Moon and a 4x4 gravity field as the perturbing forces. The definition of the force model and various force model parameters maybe modified in the OGOPT subdeck:

$$\left.\begin{array}{l}\text{NCBODY}\\ \text{CBODY}\end{array}\right\}\text{Point mass gravitational force}$$

$$\left.\begin{array}{l}\text{MAXORDEQ}\\ \text{MAXDEGEQ}\\ \text{HARMONIC}\\ \text{CNM}\\ \text{SNM}\\ \text{AUTOFORC}\end{array}\right\}\text{nonspherical gravitational force}$$

$$\left.\begin{array}{l}\text{DRAG}\\ \text{AVRDRAG}\\ \text{DRAGPAR}\\ \text{NPQPAR}\\ \text{ATMOSDEN}\end{array}\right\}\text{Atmospheric drag}$$

$$\left.\begin{array}{l}\text{SOLRAD}\\ \text{SCPARAM}\\ \text{SCPARAM2}\end{array}\right\}\text{solar radiation pressure}$$

$$\left.\begin{array}{l}\text{AVRHARM}\\ \text{AVRTHIRD}\\ \text{AVRTRUNC}\end{array}\right\}\text{VOP averaging}$$

$$\left.\begin{array}{l}\text{THRUST}\\ \text{THRSTCOF}\\ \text{ATTANG1}\\ \text{ATTANG2}\\ \text{ATTANG3}\end{array}\right\}\text{Thrust}$$

4.9.1 NCBODY, CBODY

These cards are part of OGOPT subdeck. The fisrt (NCBODY) is used to set noncentral bodies for each flight section and the second (CBODY) is used to set the integration central body.

Columns	Format	Description/Contents
1-8	A8	NCBODY
9-11	I 3	Flight section number
12-14	I 3	noncentral body indicator
15-17	I 3	noncentral body indicator
18-38	G21.14	noncentral body indicator
39-59	G21.14	noncentral body indicator
60-80	G21.14	noncentral body indicator

If one needs more than 5 noncentral bodies per section (up to 8) then another NCBODY card may be added. See codes in following Table.
Remark: To turn the effects of Sun and Moon off, one must give the following card

```
NCBODY    1  0  0
```

Index	Body
1	Earth
2	moon
3	Sun
4	Mars
5	Jupiter
6	Saturn
7	Uranus
8	Neptune
9	Pluto
10	Mercury
11	Venus

Columns	Format	Description/Contents
1-8	A8	CBODY
9-11	I 3	Flight section I
12-14	I 3	Flight section J
15-17	I 3	Flight section K
18-38	G21.14	Body number for section I
39-59	G21.14	Body number for section J
60-80	G21.14	Body number for section K

If one needs more than 3 sections (up to 10) use multiple cards. See body number in the previous table.

4.9.2 MAXDEGEQ/MAXORDEQ

These two cards are part of OGOPT subdeck. The MAXDEGEQ/MAXORDEQ is used to set the maximum degree/order (respectively) of the nonspherical potential used for the equations of motion.

Columns	Format	Description/Contents
1-8	A8	MAXDEGEQ
9-11	I 3	Flight section I
12-14	I 3	Flight section J
15-17	I 3	Flight section K
18-38	G21.14	Maximum degree of potential for section I (range 0 to 50) default = 4
39-59	G21.14	same for section J
60-80	G21.14	same for section K

Columns	Format	Description/Contents
1-8	A8	MAXORDEQ
9-11	I 3	Flight section I
12-14	I 3	Flight section J
15-17	I 3	Flight section K
18-38	G21-14	Maximum order for section I (range 0 to 50) default = 4
39-59	G21-14	same for section J
60-80	G21-14	same for section K

4.9.3 HARMONIC, CNM, SNM

These three cards are part of OGOPT subdeck. The first card, HARMONIC, is used to give an entire harmonics field table (C_{nm} or S_{nm}). Multiple keyword cards are normally used to change an entire harmonics field. The keyword need only appear on the first card. All cards to follow are considered HARMONIC until a card with 3 on column 11, signifying the end of table. The harmonics must appear in the following order:

$$
\begin{array}{llll}
C_{20}, & C_{30}, \cdots, & C_{N0} & \\
C_{21}, & C_{31}, \cdots, & C_{N1} & \\
C_{22}, & C_{32}, \cdots, & C_{N2} & \\
 & C_{33}, \cdots, & C_{N3} & \\
 & \ddots & & \\
 & & C_{NM} & (n \geq m,\ n \leq N,\ m \leq M)
\end{array}
$$

Similarly for S_{nm}
$n = 2, 3, \cdots, N$
$m = 1, 2, \cdots, M$
$n \geq m$.
Harmonics for multiple bodies can be changed by repeating the card HARMONIC with the appropirate body specified in columns 15-17.

To change a specific C_{nm} or S_{nm}, we use CNM, SNM cards (respectively).

Columns	Format		Description/Contents
1-8	A8		HARMONIC
9-11	I3	1	for C_{nm}
		2	for S_{nm}
		3	for end
12-14	I3		N degree (≤ 50)
15-17	I3		index of body
		1	- Earth
		2	- moon
18-38	G21.14		value of the i^{th} harmonic for the body specified
39-59	G21.14		value of the $(i+1)^{st}$ harmonic for the body specified
60-80	G21.14		value of the $(i+2)^{nd}$ harmonic for the body specified.

Columns	Format		Description/Contents
1-8	A8		CNM or SNM
9-11	I3		options:
		1	Solve for specified harmonic using prestored value as a-priori value
		2	Solve for specified harmonic using the value in columns 18-38 as a- priori value
		3	update prestored value with that in columns 18-38
		4	consider specified harmonic using prestored value
		5	consider specified harmonic using value in columns 18-38 as its updated value
12-14	I 3	N	index
15-17	I 3	M	index
18-38	G21.14		value of C_{NM} or S_{NM} respectively
39-59	G21.14		standard deviation of C_{NM}
60-80	G21.14		central body for harmonic coefficient
		1	Earth
		2	moon

Notes: In EPHEM runs, 1 or 4 in column 11 means: compute partial derivatives with respect to specified harmonic using prestored value; 2 or 5 in column 11 means: update harmonic coefficient **and** compute partial derivative.
In DC runs, 1, 2, 4, or 5 means: compute the partial derviatives of state with respect to the specified harmonic.

4.9.4 AUTOFORC

This card, part of OGOPT subdeck, is used to set the high-order resonance and automatic selection of spherical harmonic field options.

Columns	Format		Description/Contents
1-8	A8		AUTOFORC
9-11	I 3		High-order resonant central body spherical harmonics:
		0	option is as in the previous case if any, otherwise off.
		1	on
		2	off (default)
12-14	I 3		Automatic selection of the low-order central body spherical harmonic field
		0	option is as in the previous case if any, otherwise off.
		1	on
		2	on with user defined minimum degree and order or their default value.
		3	on with used defined maximum degree and order or their default value.
		4	off (default) This option is **not** available for central bodies other than the Earth and **cannot** be used with the averaged orbit generator.
15-80			unused

4.9.5 DRAG, AVRDRAG, DRAGPAR, DRAGPAR2

These cards, part of OGOPT subdeck, are used to set the drag force model option (DRAG), second order averaging option (AVRDRAG), update drag solve-for parameters (DRAGPAR), or set atmospheric drag options associated with DC process (DRAGPAR2).

Columns	Format		Description/Contents
1-8	A8		DRAG
9-11	I3		Flight section I
12-14	I3		Flight section J
15-17	I3		Flight section K
18-38	G21.14	1.0	include drag option for section I
		2.0	(default) do NOT include drag
39-59	G21.14		similarly for section J
60-80	G21.14		similarly for section K

Note that a spacecraft area and mass <u>must</u> be specified on the SCPARAM card.

Columns	Format		Description/Contents
1-8	A8		AVRDRAG
9-11	I3		Second order drag effects (IDRDR)
		0	Iszak's J_2 height correction (default)
		1	J_2-drag
		2	J_2-drag, drag-drag
		3	J_2-drag, drag-drag, numeric drag-J_2
		4	J_2-drag, drag-drag, analytic drag-J_2
		5	Iszak's J_2 height correction, analytic drag-J_2
12-14	I3		number of frequencies for the J_2 short periodics used in computing the mean element rates (JSPJ2)
		4	default
15-17	I3		number of frequencies for the drag short periodics used in computing the mean element rates (JSPDRG)
		4	default
18-80			unused

Columns	Format		Description/Contents
1-8	A8		DRAGPAR
9-11	I3		Drag options:
		0	- no drag solve-for requested
		1	- solve for drag parameter ρ_1 using prestored value [1]
		2	- solve for ρ_1 using value in columns 18-38 [2]
		3	- update value of drag parameter specified in columns 12-14
		4	- consider ρ_1 using prestored value [1]
		5	- consider ρ_1 using value in columns 18-38 [2]
		6	- solve for the appropriate drag parameter in a NORAD GP theory DC
12-14	I3		not used in GP theory
			parameter to be updated:
		0	-C_d drag coefficient (default = 2.0)
		1	- ρ_1 variation in drag coefficient (default =0.0)
		2	- ρ_2 time variation in atmospheric density (default = 0.0)
		3	- ρ_3 diurnal variation in atmospheric density (default =0.0)
		4	- ρ_4^1 angle between sunline and apex of diurnal atmospheric bulge (default = 30.0 degrees)
		5	- N power of cosine term (default = 6)
15-17	I3		not used in GP theory
			the power N if column 14 is 5
18-38	G21.14		not used in GP theory
			value of drag parameter to be updated if column 14 is < 5
39-59	G21.14		not used in GP theory
60-80	G21.14		optional a-priori standard deviation of the drag solve-for parameter

1. In EPHEM runs, this option becomes: compute partial derivatives of state with

respect to ρ_1 using prestored value.

2. In EPHEM runs, this option becomes: update ρ_1 and compute partial derivatives of state with respect to updated value.

Note: If the user has not supplied DRAG card and DRAGPAR specifies that ρ_1 is to be solved-for or considered, then the drag option will be automatically invoked.

Columns	Format		Description/Contents
1-8	A8		DRAGPAR2
9-11	I3		Harris-Priester atmospheric model
		1	- Standard GTDS model (default)
		1	- Full adaptive model
12-14	I3		Atmospheric drag solve option
			with high precision orbit generator
		0	- solve for ρ_1
		1	- solve for C_D
			with averaged orbit generator
		0	- no
		1	- solve for C_D
		2	- solve for C_D and A_1 in the adaptive Harris-Priester model
		3	- solve for C_D, A_1 and A_2 in the adaptive Harris-Priester model
		4	- solve for C_D, A_1, A_3 and A_4 in the adaptive Harris-Priester model
		5	- solve for C_D, A_1, A_2, A_3 and A_4 in the adaptive Harris-Priester model
15-17	I3		not used
18-38	G21.14		not used
39-59	G21.14		not used
60-80	G21.14		not used

Notes:

1. A DRAGPAR card must also be included to solve for any atmospheric drag parameters.

2. The adaptive model

$$C_D = C_{drag}\left(1 + A_1 t + A_2 t^2 + A_3 \sin \omega_s t + A_4 \cos \omega_s t\right)$$

where C_{drag} is the constant drag coefficient, t is the time in days from epoch and ω_s is the rotation rate of the Sun in radians per day.

4.9.6 NPQPAR

The Brouwer-Lyddane theory was developed for use with drag-free orbits. However, for high altitude, small eccentricity orbits the primary effect of drag is a secular change in the mean anomaly. This effect is relatively small and is noticeable only over a long period of time. Consequently, an optional first order correction to the mean anomaly is included in the form

$$\Delta M_{DRAG} = \sum_{q=0}^{m} \sum_{p=2}^{3} N_{pq}(t - t_q)^p, \qquad m = 0, 1, \ldots, 13$$

where N_{pq} are the Brouwer drag parameters and t_q is the reference time associated with those.

The following card, NPQPAR is part of OGOPT subdeck and is used to set Brouwer drag coefficients values and solve-for switches.

Columns	Format		Description/Contents
1-8	A8		NPQPAR
9-11	I 3		N_{pq} solve-for indicator
		1	don't solve for
		2	solve for
12-14	I 3		p value
		2	first order
		3	second order
15-17	I 3		q value (0-13)
18-38	G21.14		Epoch time associated with this N_{pq} (for DC only)
39-59	G21.14		a-priori value of N_{pq} (default = 0.)
60-80	G21.14		advance epoch time for N_{pq} for DC or epoch time for EPHEM (if no epoch advance, must repeat value in 18-38)

A maximum of 14 NPQPAR cards can be included for a varity of p and q values in ascending order.

4.9.7 ATMOSDEN

This card, part of OGOPT subdeck, is used to supply atmospheric density table in GTDS or DODS format and to specify the density model.

Columns	Format		Description/Contents
1-8	A8		ATMOSDEN
9-11	I 3		Density table entry number (0-60)
		0	indicates no table
12-14	I 3	nonblank	- table in DODS format (I3/3(G14.8,1x))
15-17	I 3		atmospheric density model
		1	- Jacchia - Roberts
		2	- (default) Harris - Priester
18-38	G21.14		height in km
39-59	G21.14		minimum density $\left(\frac{kg}{km^3}\right)$ at that height
60-80	G21.14		maximum density $\left(\frac{kg}{km^3}\right)$ at that height

Note that only Harris-Priester model requires a table. Clearly 60 cards must be given for the 60 various heights.

4.9.8 SCPARAM, SCPARAM2, SOLRAD

These three cards are part of OGOPT subdeck. SCPARAM is used to set spacecraft parameters necessary for drag and solar radiation options. SCPARAM2 is used to set cylindrical spacecraft parameters and paddle configuration. This card should **not** be used unless the attitude of the satellite is specified on ATTANG1 or ATTANG2 cards. The SOLRAD card is used to set the force model solar radiation switch for each flight section.

Columns	Format	Description/Contents
1-8	A8	SCPARAM
9-17	3 I 3	blank
18-38	G21.14	average cross sectional area (km^2) used for solar radiation and drag computation (see sections 3.4, 3.5 in Danielson, Neta, Early)
39-59	G21.14	spacecraft mass (kg)
60-80	G21.14	Diameter of the spacecraft body (km) default = spherical configuration computed from cross-sectional area

Columns	Format	Description/Contents
1-8	A8	SCPARAM2
9-17	3 I 3	unused
18-38	G21.14	satellite length (km^2)
39-59	G21.14	satellite paddle area (km^2)
60-80	G21.14	Angle (degrees) between satellite axis and paddles

Columns	Format	Description/Contents
1-8	A8	SOLRAD
9-11	I 3	Flight section I
12-14	I 3	Flight section J
15-17	I 3	Flight section K
18-38	G21.14	solar radiation switch for section I
39-59	G21.14	solar radiation switch for section J
60-80	G21.14	solar radiation switch for section K

Switch values:

1 - include solar radiation effects for the specified section
2 - (default) ignore solar radiation

Note: A spacecraft area and mass must be specified by SCPARAM/SCPARAM2 when switch is 1.

4.9.9 AVRHARM, AVRTHIRD, AVRTRUNC

These three cards are part of OGOPT subdeck. AVRHARM is used to set central body spherical harmonic perturbation options for the VOP averaging. AVRTHIRD is used to set third body perturbation option for VOP averaging. The last card, AVRTRUNC, is used to set the tolerance used by the VOP averaging in truncating power series expansions for the analytically averaged potentials.

Columns	Format		Description/Contents
1-8	A8		AVRHARM
9-11	I3		Central body spherical harmonic averaging
		0	automatically (default)
		1	time-dependent numerical averaging
		2	time-independent numerical averaging
		3	analytical averaging
12-14	I3		Maximum power of e in the analytical power series expansion for the averaged zonal and nonresonant tesseral
		0	automatically (default)
		-1	zero power
		≥ 1	given power
15-17	I3		Maximum power of e in the analytical power series expansion for the resonant tesseral
		0	automatically (default)
		-1	zero power
		≥ 1	given power
18-38	G21.14		high order resonant tesseral harmonic averaging option
		0	same as previous case or default if no prior
		1	time-dependent numerical averaging
		2	analytical averaging (default)

Columns	Format		Description/Contents
39-59	G21.14		Iszak's J_2 correction to height in the drag quadrature
		0	same as previous case or default if no prior
		1	on (default)
		2	off
60-80	G21.14		second order J_2 perturbation
		0	same as previous case or default if no prior
		1	on
		2	off (default)

Columns	Format		Description/Contents
1-8	A8		AVRTHIRD
9-11	I3		Third body averaging
		0	automatically (default)
		1	time-dependent numerical averaging
		2	time-independent numerical averaging
		3	analytical averaging
12-14	I3		Maximum power of a/r in the analytical power series expansion for the averaged potential of the major noncentral body
		0	automatically (default)
		≥ 2	given power
15-17	I3		Maximum power of e in the above power series
		0	automatically (default)
		-1	zero power
		≥ 1	given power
18-80			unused

Here is a table of the major noncentral body associated with each central body

Central	Noncentral
Earth	Moon
Moon	Earth
Mercury	Sun
Venus	Sun
Mars	Sun

If the central body is not in the table above, or if the major noncentral body given in the table is not being used, then the major noncentral body is the first one, among those being used, to appear in the following list: Sun, Mercury, Venus, Earth, Moon, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto.

Columns	Format	Description/Contents
1-8	A8	AVRTRUNC
9-17		unused
18-38	G21.14	$\log_{10}$ of the truncation tolerance used by the averaged orbit generator in computing the limits of the power series expansions for the analytically averaged central body (default = -10) and third body potentials
18-80		unused

Note that if the field 18-38 is blank the defaults (as given in the following table) are restored.

10^{-10}	$a/r \leq .15$	
10^{-10}	$.15 < a/r \leq .3$	$e \leq .5$
10^{-7}	$.15 < a/r \leq .3$	$e > .5$
10^{-7}	$a/r > .3$	

4.9.10 THRUST, THRSTCOF

These cards, part of OGOPT subdeck, are used to set finite thrust option (THRUST) and coefficients of a 7^{th} degree polynomial (km/sec^2) describing the thrust.

Columns	Format		Description/Contents
1-8	A8		THRUST
9-11	I3		Flight section I
12-14	I3		Flight section J
15-17	I3		Flight section K
18-38	G21.14		Thrust option for section I
		1.0	- include thrusting effects
		2.0	- default - don't include
39-59	G21.14		similarly for section J
60-80	G21.14		similarly for section K

Note that the THRSTCOF card must be supplied for each section.

Note also that the default values of the spacecraft attitude (right ascension and declination) are both zero. These values may be set by ATTANG1, ATTANG2 cards, respectively.

Columns	Format	Description/Contents
1-8	A8	THRSTCOF
9-11	I3	Flight section I
12-14	I3	subscript for coefficient appearing in columns 18-38
15-17	I3	unused
18-38	G21.14	polynomial coefficient corresponding to given subscript
39-59	G21.14	next polynomial coefficient
60-80	G21.14	following polynomial coefficient

Note: Three consecutive coefficients are given on each card, thus the subscript in columns 12-14 is 1, 4 or 7.

4.9.11 ATTANG1, ATTANG2, ATTANG3

These cards, part of OGOPT subdeck, are used to specify the right ascension (ATTANG1) and declination (ATTANG2). The third card, (ATTANG3), is used to set polynomial or polynomial and trigonometric coefficients of roll angle landmark model.

If thrust axis direction remains constant then enter only C_1 for each angle.

If thrust axis direction changes in reference to inertial frame (especially useful if in direction of spin axis) then enter any necessary coefficients.

If thrust axis is directed along the satellite velocity vector then use yaw and pitch options (columns 15-17).

If thrust axis is directed at a constant angle with respect to the velocity vector then enter yaw and pitch options (columns 15-17) and C_1 to describe that angle.

Columns	Format		Description/Contents
1-8	A8		ATTANG1
9-11	I3		Number of coefficients
12-14	I3		Orbital reference frame switch
		1	(default) geodetic
		2	geocentric
15-17	I3	1	right ascension coefficients are given
		2	yaw coefficients are given
18-38	G21.14		C_1
39-59	G21.14		C_2
60-80	G21.14		C_3

Note a second ATTANG1 card is necessary for the C_4 and C_5 coefficients in the expansion

$$\alpha = C_1 + C_2 t + C_3 t^2 + C_4 t^3 + C_5 t^4$$

or

$$\alpha = C_1 + C_2 t + C_3 \sin(C_4 t + C_5)$$

The format of the second card is

Columns	Format	Description/Contents
1-8	A8	ATTANG1
9-17		unused
18-38	G21.14	C_4
39-59	G21.14	C_5
60-80		unused

Columns	Format		Description/Contents
1-8	A8		ATTANG2
9-11	I3		Number of coefficients describing the function
12-14	I3		Coordinate frame of attitude for modelling picture Earth-edge data
		0	- input in unrotated frame and do the DC in unrotated frame
		1	- input in unrotated frame and do the DC in rotated frame
		2	- input in rotated frame and do the DC in rotated frame
15-17	I3	1	declination
		2	pitch angle
18-38	G21.14		b_1
39-59	G21.14		b_2
60-80	G21.14		b_3

Note a second ATTANG2 card is necessary for the b_4 and b_5 coefficients in the expansion

$$\delta = b_1 + b_2t + b_3t^2 + b_4t^3 + b_5t^4$$

or

$$\delta = b_1 + b_2t + b_3\sin(b_4t + b_5)$$

The format of the second card is

Columns	Format	Description/Contents
1-8	A8	ATTANG2
9-17		unused
18-38	G21.14	b_4
39-59	G21.14	b_5
60-80		unused

Columns	Format		Description/Contents
1-8	A8		ATTANG3
9-11	I3		Number of coefficients
12-14	I3		unused
15-17	I3		polynomial or polynomial with trigonometric switch (this applies to all attitude angles)
		1	polynomial
		2	polynomial with trig
18-38	G21.14		d_1
39-59	G21.14		d_2
60-80	G21.14		d_3

Note a second ATTANG3 card is necessary for the d_4 and d_5 coefficients in the expansion

$$Roll = d_1 + d_2 t + d_3 t^2 + d_4 t^3 + d_5 t^4$$

or

$$Roll = d_1 + d_2 t + d_3 \sin(d_4 t + d_5)$$

4.10 Potential Field Models

Several potential fields are available. These can be specified by POTFIELD card as part of OGOPT subdeck. The field models are listed in the following Tables , the first of which for Earth and the second for the moon.

Columns	Format	Description/Contents
1-8	A8	POTFIELD
9-11	I3	Body for which the field to be retrieved 1 for Earth 2 for moon
12-14	I3	Potential field model number (see following tables)
15-17		unused
18-80		unused

Model	Field Name
1	SAC 1969 Standard Earth Model
2	Earth Potential for Manned Flight Computation (EPFMC)
3	GSFC Earth Model (GEM 1)
4	GSFC Earth Model (GEM 7)
5	GSFC Earth Model (GEM 9)
6	GSFC Earth Model (GEM 10B) - 21 by 21 truncation of the full model
7	WGS 72 - 12 by 12 truncation of the full model
8	GSFC Earth Model (GEM L2) - 21 by 21 truncation of the full model
9	WGS 84 - 12 by 12 truncation of the full model
10	GSFC Earth Model (GEM 10B) - 50 by 50 truncation of the full model

Model	Field Name
1	JPL 15 by 8 model
2	Lunar Potential Adopted Reference Set
3	Lunar Potential for Manned Flight Computations
4	JPL - 1 Model
5	JPL - 3 Model
6	JPL - 4 Model
7	GSFC Field 15
8	Langley Research Center 5 by 5 model

4.11 Partial Derivatives

In an EPHEM run, the partial derivatives of the state with respect to any of the 'solve-for' or 'consider' parameters can be computed and printed. These partial derivatives are computed by numerical integration of the variational equations. This option is available only for Cowell, time-regularized Cowell and VOP orbit generators. Alternatively, partial derivatives with respect to the initial state can be approximated by analytical two-body partial derivatives. This option is available for all orbit generators.

Computation of these partial derivatives is specified using the STATEPAR keyword card and further defined by ATTPAR, DRAGPAR, SOLRDPAR, STATETAB, THRSTPAR, MAXDEGVE, and MAXORDVE cards. The OUTPART card allows the printing of these partial derivatives.

4.11.1 STATETAB, STATEPAR

These two cards are part of OGOPT subdeck. STATETAB is used to set the required state parameters for either partial derivative computation or solve-for parameters. STATEPAR is used to set the state vector partial derivatives switch to compute state partials in an EPHEM deck or to indicate state solve-for parameters in a DC deck.

Columns	Format	Description/Contents
1-8	A8	STATETAB
9-11	I3	parameter type code I (see codes below)
12-14	I3	parameter type code J
15-17	I3	parameter type code K
18-38	G21.14	parameter type code L
39-59	G21.14	parameter type code M
60-80	G21.14	parameter type code N

Note: In a DC run, the default will be to compute all six partial derivatives. To reduce or change the number of unknowns, the STATETAB card is required. If no state partial derivatives are desired, this card must be given with columns 9-11 blank.

Parameter Type Code	Cartesian	Keplerian	Spherical
1	x component of position	semi major axis	right ascension
2	y component of position	eccentricity	declination
3	z component of position	inclination	vehicle flight path angle
4	x component of velocity	longitude of ascending node	azimuth
5	y component of velocity	argument of perigee	radius
6	z component of velocity	mean anomaly	velocity

Columns	Format		Description/Contents
1-8	A8		STATEPAR
9-11	I3		state solve-for parameter type:
		1	(default) Cartesian unknowns
		2	Keplerian
		3	Spherical
		4	DODS
12-14	I3		mapping of initial state covariance matrix (for orbit generator only)
		1	yes
		2	(default) no
15-17	I3		angle ϕ for DODS unknowns only
		1	argument of latitude
		2	(default) argument of perigee at epoch
		3	true anomaly + argument of perigee at epoch
		4	true anomaly + argument of perigee at time t
18-38	G21.14		argument of latitude if 1 in columns 15-17
39-59	G21.14		method of computing state partials
		1	analytic state partials
		$\neq 1$	numerical
60-80			unused

Note that if no STATETAB card is given then:

- No state partial derivatives will be computed in an EPHEM run.
- Six state partial derivatives will be solved for in a DC run. The partials are of Cartesian type unless overrideen by STATEPAR.

Note that STATETAB card can also be used to turn off state partial derivatives computation in a DC run.

4.11.2 ATTPAR

This card, part of OGOPT subdeck, is used to specify number of attitude coefficients to be solved-for or considered.

Columns	Format		Description/Contents
1-8	A8		ATTPAR
9-11	I3		total number of right ascension (or yaw) polynomial coefficients to be solved for or considered. The corresponding partials for these parameters are also computed
12-14	I3		total number of declination (or pitch) polynomial coefficients to be solved for or considered. The corresponding partials for these parameters are also computed
15-17	I3		total number of roll polynomial coefficients to be solved for or considered. The corresponding partials for these parameters (which are used only with landmark data from an Earth-stabilized satellite) are also computed. This cannot be specified in an EPHEM run.
18-38	G21.14	0	solve for the total number of coefficients in columns 9-11
		1	consider the zero order coefficient and solve for the remaining in columns 9-11
39-59	G21.14		similarly for the coefficients in columns 12-14
60-80	G21.14		similarly for the coefficients in columns 15-17

4.11.3 SOLRDPAR

This card, part of OGOPT subdeck, is used to set solar radiation options and parameters.

Columns	Format		Description/Contents
1-8	A8		SOLRDPAR
9-11	I3		solar radiation options
		0	- solar radiation parameter is neither solve for nor consider parameter
		1	- solve for solar radiation parameter using prestored value initially. In an EPHEM run, compute partials of state with respect to solar radiation parameter
		2	- solve for solar radiation parameter using initially the value in columns 18-38. In an EPHEM run, compute partial of state after updating the solar radiation parameter.
		3	- update prestored value
		4	- consider solar radiation parameter using prestored value.
		5	- consider solar radiation parameter using value in columns 18-38
12-17			unused
18-38	G21.14		solar radiation parameter (if one wants to change)
39-59	G21.14		unused
60-80	G21.14		standard deviation of solar radiation parameter

4.11.4 THRSTPAR

This card, part of OGOPT subdeck, is used to decide (for each flight section) on the number of polynomial coefficients of thrust to be solved for.

Columns	Format	Description/Contents
1-8	A8	THRSTPAR
9-11	I3	Flight section I
12-14	I3	Flight section J
15-17	I3	Flight section K
18-38	G21.14	Number of coefficients for section I
39-59	G21.14	Number of coefficients for section J
60-80	G21.14	Number of coefficients for section K

4.11.5 MAXDEGVE, MAXORDVE

These cards, part of OGOPT subdeck, are used to set the maximum degree (MAXDEGVE) and order (MAXORDVE) of the nonspherical potential in the variational equations. The maximum number of sections is 10 and thus one may need up to 4 cards.

Note that the degree and order should be less than or equal the corresponding number for the equations of motion.

Columns	Format	Description/Contents
1-8	A8	MAXDEGVE
9-11	I3	Flight section I
12-14	I3	Flight section J
15-17	I3	Flight section K
18-38	G21.14	Maximum degree for section I between 0 and 21 (default = 2)
39-59	G21.14	similarly for J
60-80	G21.14	similarly for K

Columns	Format	Description/Contents
1-8	A8	MAXORDVE
9-11	I3	Flight section I
12-14	I3	Flight section J
15-17	I3	Flight section K
18-38	G21.14	Maximum order for section I between 0 and 21 (default = 2)
39-59	G21.14	similarly for section J
60-80	G21.14	similarly for section K

4.11.6 OUTPART

This card, part of OGOPT subdeck, is used to decide which state partial derivatives to print, either Cartesian, Keplerian or spherical.

Columns	Format		Description/Contents
1-8	A8		OUTPART
9-11	I3		Flight section I
12-14	I3		Flight section J
15-17	I3		Flight section K
18-38	G21.14	1.0	(default) - print partial derivatives of Cartesian state for section I
		2.0	- Keplerian state
		3.0	- spherical state
39-59	G21.14		similarly for section J
60-80	G21.14		similarly for section K

4.12 Resonance

In this section, we discuss the two cards (part of OGOPT subdeck) relating to resonance, namely: RESNM and RESONPRD. The only resonant perturbations which can be averaged analytically are central body spherical harmonics. RESNM allows the selection of analytically averaged resonant central body spherical harmonic terms for the VOP averaged orbit generator. RESONPRD allows the user to set the minimum resonant perturbation periods for VOP averaging.

Columns	Format	Description/Contents
1-8	A8	RESNM
9-11	I3	degree of resonant central body spherical harmonic coefficient range: 2-21
12-14	I3	order of resonant central body spherical harmonic coefficient range: 1-21
15-80		unused

Columns	Format	Description/Contents
1-8	A8	RESONPRD
9-17	I3	unused
18-38	G21.14	minimum period for analytically averaged resonant perturbations in seconds default = 8640.0 seconds
39-59	G21.14	minimum period for analytically averaged resonant perturbations in satellite revolutions default = 10 revolutions minimum = 3
60-80	G21.14	unused

Note: If the period of a given perturbation is smaller than either of the two minima given on this card, the perturbation is considered to be short-period and will NOT be included in the computation of the mean element rates due to analytically resonant perturbations.

4.13 Short Periodic Cards

In this section, we discuss all cards (part of OGOPT subdeck) related to short periodics. This includes zonals and tesseral harmonics, third body point masses, atmospheric drag and solar radiation pressure as well as some second order coupling terms. The first subsection describes the card to turn on some preselcted options. This is enough (but not most efficient) for most cases. In the following sections, we describe the other cards, for those interested in more control of the input. The cards are: SPSHPER, SPOUTPUT, SPGRVFRC, SPNUMGRV, SPDRAG, SPSRP, SPTESSLC, SPZONALS, SPJ2MDLY, SPMDAILY, SPLUNARA, SPSOLARA, SPINTCOF, SPINTPOS, SSTAPGFL, SSTESTFL, SSTSPPGF, and SSTESTOU.

4.13.1 SPSHPER, SPOUTPUT

This section will describe the two cards SPSHPER and SPOUTPUT. The first card, SPSHPER, specifies the computation of the short periodics based on prestored options for several typical orbits. The second card specifies the output options.

Columns	Format		Description/Contents
1-8	A8		SPSHPER
9-11	I3		prestored short periodic option
		1	mean elements only all short periodic models are turned off
		2	Low Altitude, Near Circular Orbit (Moderate Accuracy Option) J_2 Short Periodics Tesseral M-Dailies
		3	Low Altitude, Near Circular Orbit (Improved Accuracy Option) Zonal Short Periodics Tesseral M-Dailies Tesseral Linear Combinations J_2^2 terms J_2 Secular/Tesseral M-Daily Coupling
		4	24 hour Geosynchronous Orbit (Moderate Accuracy) J_2 Short Periodics Lunar-Solar Short Periodics
		5	12 hour high eccentricity Molniya Orbit (Moderate Accuracy) J_2 Short Periodics Tesseral M-Dailies Lunar-Solar Short Periodics
		6	Allow processing of individual short periodic option cards in a second OGOPT subdeck
12-80			unused

If one of the options (1-5) are selected than any short periodic cards relating to the force model in this subdeck will be ignored.

In the following 5 Tables, we list the setting of some variables for each of the options.

Mean Elements	option 1
Variable	value
IZONAL	3
IMDALY	3
ITESS	3
ITHIRD	3
IJ2J2	3
IJ2MD	3
IDRAG	0
ISOLAR	0

Low Altitude	option 2
Variable	value
IZONAL	1
IMDALY	1
ITESS	3
ITHIRD	3
IJ2J2	3
IJ2MD	3
IDRAG	0
ISOLAR	0
NZN	2
LZN	1
JZN	5
NMD	minimum of INDEG and 12
MMD	minimum of INORD and 12
LMD	minimum of (NMD-2) and 4

Low Altitude Variable	option 3 value
IZONAL	1
IMDALY	1
ITESS	1
ITHIRD	3
IJ2J2	1
IJ2MD	1
IDRAG	0
ISOLAR	0
NZN	minimum of INDEG and 12
LZN	minimum of (NZN-1) and 4
JZN	minimum of (2 NZN+1) and (NZN +4)
NMD	minimum of INDEG and 12
MMD	minimum of INORD and 12
LMD	minimum of (NMD-2) and 4
NJ2MD	minimum of NMD and 4
MJ2MD	minimum of MMD and 4
LJ2MD	NJ2MD-2
NTS	minimum of INDEG and 8
MTS	minimum of INORD and 8
LTS	4
LTSHAN	2
JMINTS	(- NTS - LTS)
JMAXTS	(NTS + LTS)

Geosynchronous	option 4
Variable	value
IZONAL	1
IMDALY	3
ITESS	3
ITHIRD	1
IJ2J2	3
IJ2MD	3
IDRAG	0
ISOLAR	0
NZN	2
LZN	1
JZN	5
NTH(1)	8
JMAXTH(1)	9
LTH(1)	4
ITDTH(1)	2
NTDTH(1)	0
NTH(2)	4
JMAXTH(2)	5
LTH(2)	4
ITDTH(2)	2
NTDTH(2)	0

Molniya	option 5
Variable	value
IZONAL	1
IMDALY	1
ITESS	3
ITHIRD	1
IJ2J2	3
IJ2MD	3
IDRAG	0
ISOLAR	0
NZN	minimum of INDEG and 4
LZN	NZN-1
JZN	2 NZN + 1
NMD	minimum of INDEG and 4
MMD	minimum af INORD and 4
LMD	NMD - 2
NTH(1)	8
JMAXTH(1)	9
LTH(1)	4
ITDTH(1)	2
NTDTH(1)	0
NTH(2)	4
JMAXTH(2)	5
LTH(2)	4
ITDTH(2)	2
NTDTH(2)	0

Columns	Format		Description/Contents
1-8	A8		SPOUTPUT
9-11	I3		print the coefficients of the position and velocity interpolator (KINTPV)
		1	yes
		2	no (default)
12-14	I3		print the coefficients of the short periodic interpolator (KINTCF)
		1	yes
		2	no (default)
15-17	I3		print short periodic variations (KSP)
		1	yes
		2	no (default)
18-38	G21.14		print Fourier coefficients of the short-periodic variations (KSPCF) These are very useful in understanding the size and frequency of the short periodics
		1	yes
		2	no (default)
39-80			unused

4.13.2 SPGRVFRC, SPNUMGRV

These cards are used to set the gravitational force model options for the Fourier coefficients in the short periodic expansions of the semianalytic satellite theory (SPGRVFRC), and the numerical gravity options for those coefficients (SPNUMGRV).

Columns	Format		Description/Contents
1-8	A8		SPGRVFRC
9-11	I3		central body zonal harmonic short periodic option
		1	analytical coefficients (default)
		2	numerical coefficients
		3	off
12-14	I3		central body m-daily tesseral harmonic short periodic option
		1	analytical coefficients (default)
		3	off
15-17	I3		central body high frequency (linear combination term) tesseral short periodic option
		1	analytical coefficients (default)
		3	off
18-38	G21.14		third body short periodic option
		1	analytical coefficients (default)
		2	numerical coefficients
		3	off
39-59	G21.14		central body J_2^2 short periodic option
		1	analytical coefficients (default)
		3	off
60-80	G21.14		central body J_2 secular/tesseral m-daily coupling short periodic option
		1	analytical coefficients (default)
		3	off

Columns	Format		Description/Contents
1-8	A8		SPNUMGRV
9-11	I3		quadrature order for numerical gravity short periodic (NGRAV)
		1	12 point quadrature
		2	16 point quadrature
		3	20 point quadrature
		4	24 point quadrature
		5	32 point quadrature
		6	40 point quadrature
		7	48 point quadrature (default)
12-14	I3		short periodic expansion longitude for numerical gravity (LGRAV)
		1	mean longitude (default)
		2	eccentric longitude
		3	true longitude
15-17	I3		maximum frequencies for numerical gravity (JGRAV)
		6	default
18-38	G21.14		method of computing Fourier coefficient time derivatives for the numerical gravity perturbations (IDGRAV)
		1	numerical quadrature
		2	finite differences (default)
		3	off
39-59	G21.14		order of highest time derivative for gravitational perturbations (NDGRAV)
		0	default
60-80	G21.14		time step for numerical time derivatives (DTGRAV)
			3600 seconds (default)

4.13.3 SPDRAG, SPSRP, SPTESSLC, SPZONALS

In this subsection, we discuss four cards SPDRAG, SPSRP, SPTESSLC, and SPZONALS. The SPDRAG card is used to set the atmospheric drag options for the Fourier coefficients in the short periodic exapnsions. Note that in all the automatic cases (SPSHPER card), the drag short periodic is off. The SPSRP card is used to set the solar radiation pressure option for the short periodics. The SPTESSLC card is used to set the central body high frequency tesseral harmonic options for the short periodic exapansions. The last card, SPZONALS, is used to set the central body zonal harmonic options for the short periodics.

Columns	Format		Description/Contents
1-8	A8		SPDRAG
9-11	I3		quadrature control switch for atmospheric drag short periodic (IDRAG)
		0	do not include drag short periodics
		1	include drag short periodics (default)
12-14	I3		quadrature order for drag short periodics (NDRAG)
		1	12 point quadrature
		2	16 point quadrature
		3	20 point quadrature
		4	24 point quadrature
		5	32 point quadrature
		6	40 point quadrature
		7	48 point quadrature (default)
15-17	I3		short periodic expansion longitude for drag (LDRAG)
		1	mean longitude (default)
		2	eccentric longitude
		3	true longitude
18-38	G21.14		maximum frequency for drag (JDRAG)
		6	(default)
39-80			unused

Columns	Format		Description/Contents
1-8	A8		SPSRP
9-11	I3		quadrature control switch for solar radiation pressure short periodic (ISOLAR)
		0	do not include solar radiation pressure short periodics
		1	include solar radiation pressure short periodics (default, if included in mean elements)
12-14	I3		quadrature order for solar radiation pressure short periodics (NSOLAR)
		1	12 point quadrature
		2	16 point quadrature
		3	20 point quadrature
		4	24 point quadrature
		5	32 point quadrature
		6	40 point quadrature
		7	48 point quadrature (default)
15-17	I3		short periodic expansion longitude for solar radiation pressure (LSOLAR)
		1	mean longitude (default)
		2	eccentric longitude
		3	true longitude
18-38	G21.14		maximum frequency for solar radiation pressure (JSOLAR)
		6	(default)
39-80			unused

Columns	Format	Description/Contents
1-8	A8	SPTESSLC
9-11	I3	maximum degree of the central body high frequency tesseral field (NTS) NTS can vary between 2 and 21 The default for NTS is the maximum degree on MAXDEGEQ card or its default
12-14	I3	maximum order of the central body high frequency tesseral filed (MTS) MTS can vary between 1 and NTS The default for MTS is the maximum order on MAXORDEQ card or its default
15-17	I3	maximum d'Alembert characteristic (power of eccentricity outside Hansen coefficients) (LTS) LTS should be approximately 2 * LTSHAN (see next parameter) The default for LTS is 4 (designed for near circular orbit)
18-38	G21.14	maximum power of e^2 in the power series expansion for the Hansen coefficients (LTSHAN) The default for LTSHAN is 2 (designed for near circular orbit)
39-59		minimum frequency in λ (mean longitude) in the central body high frequency tesseral field (JMINTS) The default for JMINTS is (-NTS-LTS) It is <u>recommended</u> that JMINTS and JMAXTS be equal in magnitude
60-80		maximum frequency in λ (mean longitude) in the central body high frequency tesseral field (JMAXTS) The default for JMAXTS is NTS+LTS It is <u>recommended</u> that JMINTS and JMAXTS be equal in magnitude

Remark: There is a restriction $(JMAXTS - JMINTS + 1) * MTS \leq 1600$.

Columns	Format	Description/Contents
1-8	A8	SPZONALS
9-11	I3	maximum power of r/a (NZN) NZN can vary between 2 and 21 The default for NZN is the maximum degree on MAXDEGEQ card or its default
12-14	I3	maximum power of e (LZN) LZN can vary between 0 and (NZN-1) The default for LZN is one less than the maximum degree on MAXDEGEQ card or its default
15-17	I3	maximum frequency in true longitude L (JZN) JZN is between 1 and (2*NZN+1) The default for JZN is the maximum degree on MAXDEGEQ card or its default
18-80	G21.14	unused

4.13.4 SPJ2MDLY, SPMDAILY, SPLUNARA, SPSOLARA

In this subsection, the following four cards are detailed: SPJ2MDLY, SPMDAILY, SPLUNARA, SPSOLARA. The first card, SPJ2MDLY, is used to set the central body J_2 secular/tesseral m-daily coupling harmonic options for the Fourier coefficients in the short periodic expansions. The second card, SPMDAILY, is used to set the central body m-daily tesseral harmonic options. The last two cards are used to set the solar (SPSOLARA) or lunar (SPLUNARA) third body high frequency options.

Columns	Format		Description/Contents
1-8	A8		SPJ2MDLY
9-11	I3		maximum degree of the central body J_2 secular/tesseral m-daily coupling (NJ2MD) NJ2MD can vary between 2 and 21 The default for NJ2MD is the maximum degree NMD specified for the tesseral m-daily field (see SPMDAILY card)
12-14	I3		maximum order of the central body J_2 secular/tesseral m-daily coupling (MJ2MD) MJ2MD can vary between 1 and NJ2MD The default for MJ2MD is the maximum order MMD specified for the tesseral m-daily field
15-17	I3		maximum power of e (LJ2MD) LJ2MD is between 0 and (NJ2MD-2) The default for LJ2MD is (NMD-2) (see SPMDAILY card)
18-38	G21.14		use drag secular/tesseral m-daily coupling (IDRMD)
		1	yes (default)
		2	no
39-80			unused

Columns	Format	Description/Contents
1-8	A8	SPMDAILY
9-11	I3	maximum degree of the central body tesseral m-daily (NMD) NMD can vary between 2 and 21 The default for NMD is the maximum degree specified on MAXDEGEQ card or its default
12-14	I3	maximum order of the central body tesseral m-daily (MMD) MMD can vary between 1 and NMD The default for MMD is the maximum order specified on MAXORDEQ card or its default
15-17	I3	maximum power of e (LMD) LMD is between 0 and (NMD-2) The default for LMD is (NMD-2)
18-80		unused

Columns	Format		Description/Contents
1-8	A8		SPLUNARA
9-11	I3		maximum power of a/r (NTH(1)) NTH(1) can vary between 2 and 20 The default is 8
12-14	I3		maximum frequency in eccentric longitude F (JMAXTH(1)) JMAXTH(1) can vary between 1 and NTH(1)+1 The default is the maximum
15-17	I3		maximum power of e (LTH(1)) LTH(1) is between 0 and (NTH(1)+JMAXTH(1)) The default is the maximum
18-38			method of coupling time derivatives (ITDTH(1)
		1	analytical
		2	finite differences (default)
39-59	G21.14		order of the highest time derivative (NTDTH(1)
		0	default
60-80			unused

Columns	Format		Description/Contents
1-8	A8		SPSOLARA
9-11	I3		maximum power of a/r (NTH(2)) NTH(2) can vary between 2 and 20 The default is 4
12-14	I3		maximum frequency in eccentric longitude F (JMAXTH(2)) JMAXTH(2) can vary between 1 and NTH(2)+1 The default is the maximum
15-17	I3		maximum power of e (LTH(2)) LTH(2) is between 0 and (NTH(2)+JMAXTH(2)) The default is the maximum
18-38			method of coupling time derivatives (ITDTH(2)
		1	analytical
		2	finite differences (default)
39-59	G21.14		order of the highest time derivative (NTDTH(2)
		0	default
60-80			unused

4.13.5 SPINTCOF, SPINTPOS

In this subsection, we detail the two cards for the interpolator in the short periodic. The first card, SPINTCOF, sets interpolator options for the Fourier coefficients in the short periodic expansions, and the second, SPINTPOS, sets the interpolator options for position, velocity and their partial derivatives.

Columns	Format		Description/Contents
1-8	A8		SPINTCOF
9-11	I3		interpolate for the Fourier coefficients?
		1	yes (default)
		2	no
12-14	I3		number of time points for the Lagrangian interpolator
		1	1 point formula
		2	2 point formula
		3	3 point formula (default)
		4	4 point formula
15-17	I3		unused
18-38			nominal interval in seconds between interpolator points Not operational since currently Runge-Kutta integrator must be used, the interval is the same as the RK stepsize
39-80			unused

Columns	Format		Description/Contents
1-8	A8		SPINTPOS
9-11	I3		interpolate for the position, velocity and partial derivatives?
		1	yes
		2	no (default)
12-14	I3		number of time points for the Hermite interpolators
		2	2 point formula
		3	3 point formula (default)
15-17	I3		unused
18-38			nominal interval in seconds between interpolator points default is 120 seconds
39-80			unused

4.13.6 SSTAPGFL, SSTESTFL, SSTSPPGF, SSTESTOU

In this subsection, the four cards related to short periodic partial derivatives, namely: SSTAPGFL, SSTESTFL, SSTSPPGF, and SSTESTOU will be described. The first card, SSTAPGFL, is used to set the perturbations included in the element rate partial derivatives. The card SSTESTFL is used to set the primary computational options for the partial derivatives. The cards SSTSPPGF is used to set the perturbations to be included in the short periodic partial derivatives. The last cards, SSTESTOU, is used to set the output options for the partial derivatives.

Columns	Format		Description/Contents
1-8	A8		SSTAPGFL
9-11	I3		include the central body gravitatonal field in the element rate partial? (ICBVAR)
		0	no
		1	analytically
		2	finite differences using the degree and order in the averaged equations of motion
		3	finite differences using degree 4 and order 0
12-14	I3		include the J_2^2 central body gravitational field effects in the element rate partial? (J22VAR)
		0	no
		1	finite differences
15-17	I3		include third body gravitational field in the element rate partials? (ITBVAR)
		0	no
		1	finite differences
18-38	G21.14		include atmospheric drag in the element rate partials? (IDRVAR)
		0	no
		1	finite differences
39-59	G21.14		include second order atmospheric drag in the element rate partials? (IDRDRV)
		0	no
		1	J_2-drag
		2	J_2-drag, drag-drag
		3	J_2-drag, drag-drag, numeric drag-J_2
		4	J_2-drag, drag-drag, analytic drag-J_2
		5	Iszak J_2 height correction, analytic drag-J_2
		6	Iszak J_2 height correction
60-80	G21.14		ISRVAR Include solar radiation pressure?
		0	no
		1	finite differences
		2	numerical quadrature (Not operational)

Columns	Format		Description/Contents
1-8	A8		SSTESTFL
9-11	I3		compute element rate partials analytically? (IANAL)
		0	no
		1	A matrix only (default)
		2	D matrix only
		3	both A and D
12-14	I3		compute element rate partials using finite differences? (IDIFF)
		0	no (default)
		1	A matrix only
		2	D matrix only
		3	both A and D
15-17	I3		compute element rate partials using numerical quadrature? (IQDRT)
		0	no (default)
		1	A matrix only (Not operational)
		2	D matrix only (Not operational)
		3	both A and D (Not operational)
18-38	G21.14		compute short periodic partial derivatives?
		0	no (default)
		1	B_1 matrix only
		2	both B_1 and B_4
		3	B_4 matrix only
39-80			unused

Remarks:

1. The A matrix is comprised of the partial derivatives of element rate with respect to elements

2. The D matrix is comprised of the partial derivatives of element rate with respect to the dynamic parameters

3. The B_1 matrix is comprised of the partial derivatives of element rate with respect to mean elemens

4. The B_2 matrix is comprised of the partial derivatives of the mean elements with respect to the epoch mean elements (mean element state transition matrix)

5. The B_3 matrix is comprised of the partial derivatives of the mean elements with respect to the dynamic parameters

6. The B_4 matrix is comprised of the partial derivatives of the short periodics with respect to the dynamic parameters

Columns	Format		Description/Contents
1-8	A8		SSTSPPGF
9-11	I3		include the central body gravitational field in the short periodic partial, using the degree and order used in the averaged equations of motion? (KGRAVP)
		0	no
		1	analytically (J_2 only)
		2	finite differences (full field)
12-14	I3		include the central body gravitational field in the short periodic partial, using the degree NZONP and 0 order ? (KZONP)
		0	no
		1	analytically (J_2 only)
		2	finite differences (full field)
15-17	I3		include third body gravitational field in the short periodic partials? (KTHRP)
		0	no
		2	finite differences
18-38	G21.14		include atmospheric drag in the short periodic partials? (KDRAGP)
		0	no
		2	finite differences
39-59	G21.14		include solar radiation pressure in the short periodic partials? (KSOLRP)
		0	no
		2	finite differences
60-80	G21.14		maximum degree of the central body gravitational field used in computing the short periodic partials (NZONP) used only if KZONP=2

Columns	Format		Description/Contents
1-8	A8		SSTESTOU
9-11	I3		print the B_1 matrix? (KPRTB1)
		1	yes
		2	no
12-14	I3		print the B_2 matrix? (KPRTB2)
			mean element transition matrix
		1	yes
		2	no
15-17	I3		print the B_3 matrix? (KPRTB3)
		1	yes
		2	no
18-38	G21.14		print the B_4 matrix? (KPRTB4)
		1	yes
		2	no
39-80	G21.14		unused

Chapter 5

Differential Correction (DC) Program

5.1 Introduction

The purpose of the Differential Correction (DC) Program is to estimate the values of a set of parameters, called solve-for variables, in a mathematical model of spacecraft motion. The parameters are estimated so as to minimize, in a Bayesian weighted least-squares sense, the sum of the squares of the differences between computed and observed trajectory data while constraining the parameters to satisfy their a-priori initial estimates to within a specified uncertainty [4]. The trajectory data required by the DC Program must be supplied by the user.

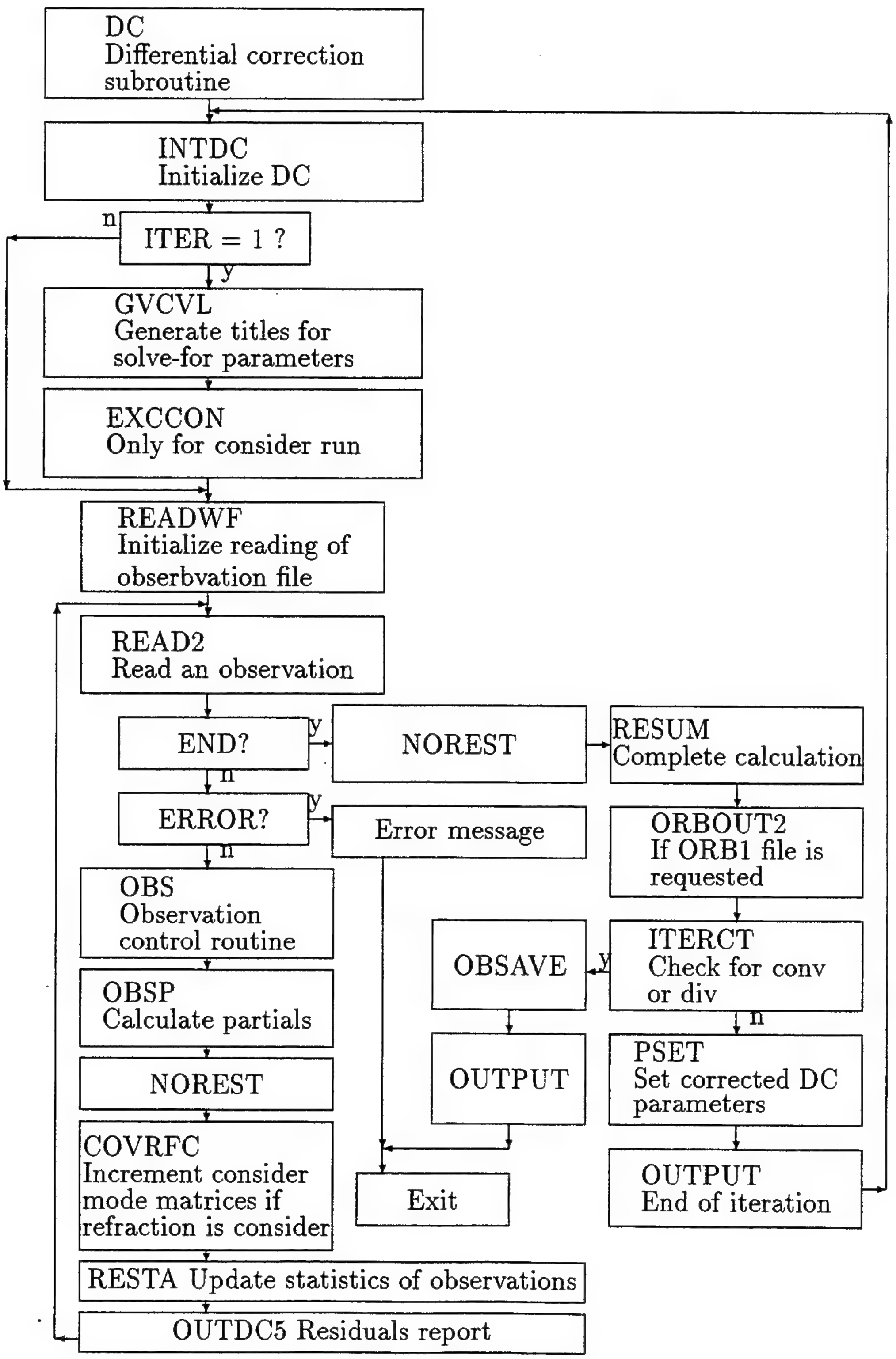
The following are components of the differential correction process:

- Initial elements and epoch
- Observation sources
- Orbit generator type and associated parameters
- Solve-for parameters
- Consider parameters
- Covariance matrix
- Variational equations for state parameters

- Observation weighting
- Convergence criteria
- Output reports
- ORBIT,ORB1 and EPHEM files

The DC Program mandatory keywords will provide information related to the first three components. If no other inputs are supplied, the DC Program will execute with default values using the Cowell orbit theory and Cartesian state vector components. If the user wants to modify any of the default values, then input is required using the DMOPT, OGOPT, and/or DCOPT subdecks.

5.2 Flowchart



5.3 Differential Correction Required Keywords

The first card in the DC Program input deck must be the CONTROL card which is used to initiate the DC Program. The mandatory keyword cards ELEMENT1, ELEMENT2, EPOCH, OBSINPUT, and ORBTYPE must follow the CONTROL card.

If any data management functions are required, the mandatory keyword cards must be followed by the DMOPT subdeck keyword, optional data management keywords, and the delimiter keyword END. If required, the subdeck keywords DCOPT and OGOPT with the proper optional keywords and END delimiters may then follow. These latter two subdecks may be in any order. The final card must be the keyword FIN which indicates the end of the deck.

5.4 Initial Elements and Epoch

The following six methods are provided for inputting initial elements and epoch into a DC Program run:

- "Punched card" input

  The keywords ELEMENT1, ELEMENT2, and EPOCH allow "punched card" input of initial elements. A description of these keyword cards was given in Section 3.

- 24-Hour Hold Elememt File

- GTDS Permanent Elements File

  Elements from a DC Program run can be stored in one of the two GTDS element files, the 24-Hour Hold Elements File or the GTDS Permanent Elements File. These elements can subsequently be used as input to a DC Program run. In this case, a user must supply, in a DMOPT subdeck, the WORKELS keyword card which defines the type of file and the element set number. When elements are supplied through the WORKELS keyword, the ELEMENT1, ELEMENT2, and EPOCH keyword cards are not required.

- DODS Permanent Elements File

  Elements from the DODS Permanent Elements File can be input directly to R&D GTDS. This is done by supplying a WORKELS keyboard card in a DMOPT subdeck. The coordinate system will be true-of-epoch, the reference central body will be the Earth, and coordinate system type will be Cartesian or Brouwer mean elements.

- Elements from a previous run

  Elements resulting from the previous execution of a R&D GTDS program (for example, in a previous DC Program execution) may be used as DC Program initial elements by placing the word INPUT or OUTPUT in the element-source field of the CONTROL card.

- Elements epoch advance

  The concept of elements epoch advance is used to propagate, i.e., advance, the elements from the given epoch at T_0 to another epoch at T_1 (the epoch needed for the DC Program run). The elements at T_1 then become the initial elements for the DC Program run. There are two methods available to the user to do this. They are:

  1. The DC automatic epoch advance option can be invoked by supplying T_1 in columns 60-80 of the DC EPOCH keyword card. The state is initialized at T_0, and the EPHEM Program is called to propagate the state to T_1 using orbit generator options specified in the input. This is performed prior to starting the DC Program.
  2. A manual advance, employing an EPHEM Program input deck followed immediately by a DC Program input deck, may also be used. To accomplish this, the EPHEM case is executed with the OUTPUT mandatory keyword card containing T_1 as the end time. The DC case is then executed with the word OUTPUT in columns 41-48 of the CONTROL card. The DC case will then require no ELEMENT1, ELEMENT2, and EPOCH keyword cards, because element and epoch information is available to the DC Program run through block COMMON.

5.5 Observation Sources

In R&D GTDS the observations can be obtained from one or more sources. The source(s) and the start and end times of the observation span to be used are specified via the OBSINPUT mandatory keyword card. All observations in the time span will be used unless a detailed edit is specified. The observations used are stored in a R&D GTDS observations working file.

5.5.1 OBSINPUT

In this subsection, we describe the OBSINPUT card which is mandatory for a DC process. This will specify the observations input sources.

Columns	Format	Description/Contents
1-8	A8	OBSINPUT
9-11	I3	Source of input observations (up to three sources in each card)
12-14	I3	Source of input observations
15-17	I3	Source of input observations
18-38	G21.14	Start time of observation span (yymmddhhmmss.ssss) (default is run epoch)
39-59	G21.14	End time of observation span (yymmddhhmmss.ssss) (default is three months later)
60-80	G21.14	Satellite ID for second satellite (for satellite-to-satellite data)

The possible sources are

1	GTDS observation tape (29)
2	GTDS observation disk (31)
3	DODS observation tape (30)
4	DODS permanent data base (32)
9	PCE ORB1 file in GTDS true of reference date coordinates (24)
11	Observations working file previously created (17)
15	PCE ORB1 file in Mean of 1950 coordinates (24)
16	PCE ORB1 file in Earth-centered Earth-fixed coordinates (24)
17	PCE ORB1 file in GTDS NORAD True of reference coordinates (24)
18	PCE position and velocity in GTDS true of reference date coordinates (15)
19	PCE position and velocity in mean of 1950 coordinates (15)
20	PCE position and velocity in Earth-centered Earth-fixed coordinates (15)
21	PCE position and velocity in NORAD true of date coordinates (15)

5.6 Orbit Generator Type and Associated Parameters

The ORBTYPE mandatory keyword card provides basic information regarding the orbit generator and associated options which will be used to provide the ephemeral data required by the differential correction process. The force model options generally used in the DC Program are the standard R&D GTDS default options, (i.e. Earth-centered system with Sun, Moon and a 4x4 gravity field in the force model). However, if a user wants to modify any of the parameter used in the orbit generator, an OGOPT subdeck with the proper optional keyword(s) is required. Types of parameters which can be modified are: force model constants and options, partial derivative options, and integration options.

5.7 Solve-For Parameters

Solve-for parameters are those parameters which are to be estimated in a DC Program run. There are two types of such parameters, dynamic solve-for parameters and local solve-for parameters.

Dynamic solve-for parameters are those which are implicit in the equations of motion and include:

- Spacecraft at epoch
- Aerodynamic force parameter
- Gravitational constants of planetary bodies
- Gravitational harmonic coefficients
- Thrust model parameters
- Attitude model parameters

Local solve-for parameters are those which are implicit in the observation models and include:

- Tracking station locations
- Observation biases (by pass)
- Station timing biases (by pass)

General restrictions on specifying solve-for parameter are as follows:

1. The maximum number of dynamic solve-for parameters is 20. If dynamic parameters are being considered, i.e., parameters being considered for statistical purposes but not being estimated, then the combined maximum number of dynamic solve-for and dynamic considered parameters is 20.

2. The maximum number of solve-for and considered parameters is 50.

3. Analytic orbit theories can solve only for state parameters and local solve-for parameters, with the following exception: An option to solve for phenomenological polynomial coefficients to account for "moderate sustained accelerations" (such as mild drag effects) to the mean anomaly of the Brouwer-Lyddane theory is specified on the NPQPAR keyword cards.

5.7.1 Dynamic Solve-for Parameters

By default in a DC Program run, the Cowell orbit theory will be used and the six Cartesian elements X_0 , Y_0 , Z_0 , $\dot{X}_0$, $\dot{Y}_0$, $\dot{Z}_0$ will be solved for. If a user wants to modify this basic set, or to solve for other dynamic parameters, then an OGOPT subdeck with the proper keyword cards must be supplied.

R&D GTDS can solve for from one to six state parameters from one of the following state parameter sets (use STATEPAR to choose)

- Cartesian X_0, Y_0, Z_0, $\dot{X}_0$, $\dot{Y}_0$, $\dot{Z}_0$
- Keplerian a, e, i, Ω, ω, M
- Spherical α, σ, ν, β, r, V
- DODS unknowns X_1, X_2, $\cdots$,X_9, X_{19}
- Brouwer mean elements
- Vinti mean elements

To solve for a subset of the state parameters set, a STATETAB keyword card with the values indicating the subset must be supplied.

To solve for no state parameters, the user must include STATEPAR and STATETAB keyword cards with a zero (0) in the integer fields.

The coefficient ρ_1 in the aerodynamic drag term of the force-model can be estimated via the use of the DRAGPAR keyword card.

When the DRAGPAR keyword is used, the drag force will be invoked for section 1 of the flight if drag has not been invoked in the force model. The spacecraft area and mass must be supplied via a SCPARAM keyword card in an OGOPT subdeck.

The solar radiation coefficient, C_r , in the solar radiation term of the force model can be estimated via the SOLRDPAR keyword card.

When the SOLRDPAR keyword is used, the solar radiation force will be invoked. The spacecraft area and mass must be supplied via SCPARAM keyword card in an OGOPT subdeck.

The Ephermeris Generation Program force model allows for a 21 x 21 potential field for the nonspherical gravitational accelerations of the Earth or the Moon. In R&D GTDS, up to 20 harmonic coefficients can be estimated. These estimated coefficients, $C_{n,m}$ and $S_{n,m}$, must:

1. Be used in the force model (i. e., the cards MAXORDEQ and MAXDEGEQ must indicate an order and degree (respectively) for the gravitational harmonics in the equations of motion at least as great as the order and degree of the coefficients being estimated),

2. Be used in the variational equations (i.e., the cards MAXORDVE and MAXDEGVE must indicate an order and degree for the gravitational harmonics in the variational equations at least as great as the order and degree of the coefficient being estimated).

The thrust acceleration is calculated in R&D GTDS using a polynomial to solve for these coefficients, the THRSTPAR keyword card must be used.

The vehicle attitude is characterized by polynomials which define the right ascension and declination of the spin axis as a function of time. To solve for these coefficients, the ATTPAR keyword card must be used. The coefficients may only be solved for, obviously, when thrust is included in the force model.

5.7.2 Local Solve-For Parameters

In most DC Program runs, local solve-for parameters are usually not estimated. When required, however, a user can solve for these local parameters, e.g., station locations, observation biases, and time biases, by including the proper keyword cards in a DCOPT subdeck. Local solve-for parameters can be estimated in conjunction with any orbit generator type. If the observation source is attitude sensor data, then only observation biases and time biases can be solved for.

5.8 Consider Parameters

Consider parameters are those model parameters that are known with only limited certainty but are not being estimated. Nevertheless, their uncertainty degrades the uncertainty (variance and covariance) of the solve-for variables. The consider mode (i.e., and execution using consider parameters) is invoked by including the CONSIDER keyword card in the DCOPT subdeck. Consider parameters can be both dynamic and local and include the following:

- Dynamic Consider Parameters
  - Aerodynamic force parameter
  - Scale factor on the solar radiation acceleration

  - Gravitational harmonic coefficients
  - Thrust model parameters
  - Attitude model parameters
- Local Consider Parameters
  - Tracking station locations
  - Observation biases (by pass)
  - Station timing biases (by pass)

Any parameter designated as a consider parameter must be invoked in the force or observation model (e.g., in order to consider the drag parameter ρ_1, drag must be included in the force model).

When specifying consider parameters, the combined total number of solve-for plus consider parameters must not exceed 50.

If the input observation source is Precision Conversion of Element (PCE) data, only dynamic consider parameters can be considered. If the observation source is attitude sensor data, only observation biases and timing biases can be considered.

5.8.1 CONSIDER

The CONSIDER card, part of OGOPT subdeck is used to invoke the consider mode in a DC run.

Columns	Format		Description/Contents
1-8	A8		CONSIDER
9-11	I3		Frequency at which the consider mode is used after the first iteration (default = 1)
12-14	I3		The first iteration to employ consider mode (default = 1)
15-17	I3		not used
18-38	G21.14	0	(default) Ignore refraction
		$\neq 0$	Consider refraction
39-59	G21.14	0	(default) Biases are nonconsider
		$\neq 0$	All biases are consider
60-80	G21.14		not used

5.9 Covariance Matrix

For a DC Program run, the a priori uncertainty of the solve-for and consider parameters is input via the covariance matrix. In R&D GTDS the a priori values of all elements of the covariance matrix default to zero. If a nonzero a priori covariance matrix is desired, the elements of the matrix must be input.

A COVARNC keyword card in the OGOPT subdeck is required to input the state covariance matrix. Because this matrix is symmetric, only the upper triangle need be input.

5.9.1 COVARNC

The COVARNC card, part of OGOPT sudeck, is used to set upper triangular part of the 6 by 6 a-priori state covariance matrix. Since the matrix is symmetric, only the upper part is required.

Columns	Format	Description/Contents
1-8	A8	COVARNC
9-11	I3	Packed row and column integer for element I
12-14	I3	Packed row and column integer for element J
15-17	I3	Packed row and column integer for element K
18-38	G21.14	Matrix element I
39-59	G21.14	Matrix element J
60-80	G21.14	Matrix element K

Note that the indices are packed so that one has 10 times the row number added to the column number.

5.10 Variational Equations for State Parameters

Whenever a dynamic parameter P is being solved for (or considered), numerical solution of the variational equations for $\partial \overline{X}/\partial P$ and $\partial \dot{\overline{X}}/\partial P$ is generally required. However, in R&D GTDS the user has the option to use an analytic solution if the parameter P is a state variable, even though the orbit theory is nonanalytic. This is done by including in the OGOPT subdeck a STATEPAR keyword card with a 1.0 in columns 39-59. In this case, the analytical partial derivatives are computed using the integrated state in a two-body analytic solution.

5.11 Observation Weighting

R&D GTDS computes an observation weight, W, for each observation type according to the following formula

$$W = \frac{\rho_F}{(C_5 \overline{\sigma}^2)}$$

where ρ_F is a geometric factor C_5 is a factor $\overline{\sigma}$ is the a priori observation standard deviation.

The nominal values of the standard deviations for various observation types can be modified by including the OBSDEV or CHWT keyword card in a DMOPT subdeck. The difference between the two is the request for statistical output report (OBSDEV is when such report is NOT requested).

The goemetric factor, ρ_F, is determined as follows

Observation Type	ρ_F
Range, elevation, range rate	$C_1 \sin E + C_2$
Azimuth	$C_3 \sin E + C_4$
Minitrack direction cosines ℓ, m	1.0-O_c^2
Others	1.0

where C_1, C_2, C_3, C_4 are local parameters, E is the computed elevation angle and O_c is the computed ℓ or m minitrack observation. Additionally, the parameter C_5 is used in calculating the weighting. These five facotrs can be modified by using the CWEIGHT keyword card in a DCOPT subdeck.

5.11.1 OBSDEV, CWEIGHT

In this section, we discuss the two cards OBSDEV, and CWEIGHT. The first is a part of DMOPT subdeck and the second is a part of DCOPT subdeck. The first card is used to set the standard deviation of the input observation noise when the statistical output report is NOT requested. The second card, CWEIGHT, is used to set weighting factor for observations.

Columns	Format	Description/Contents
1-8	A8	OBSDEV
9-11	I3	Weight index I
12-14	I3	Weight index J
15-17	I3	Weight index K
18-38	G21.14	Noise standard deviation for weight index I
39-59	G21.14	Noise standard deviation for weight index J
60-80	G21.14	Noise standard deviation for weight index K

The units for range are meters and for range rate are cm/sec.

Columns	Format	Description/Contents
1-8	A8	CWEIGHT
9-11	I3	Weighting factor index I
12-14	I3	Weighting factor index J
15-17	I3	Weighting factor index K
18-38	G21.14	Weight factor for index I
39-59	G21.14	Weight factor for index J
60-80	G21.14	Weight factor for index K

Note that there are 5 indices (C_1 - C_5, see above)

Index	Default	Description
1	0.	Elevation and range rate weighting factor (C_1)
2	1.	Bias factor for range, elevation and range-rate (C_2)
3	1.	Elevation angle gain for azimuth angle weighting factor (C_3)
4	0.	Bias facotr for azimuth angle weighting factor (C_4)
5	1.	Multiplier for observation variance in weight computation

5.12 Convergence Criteria

In R&D GTDS a DC Program run can be terminated by one of four convergence criteria as follows:

1. $|\frac{RMS_B - RMS_P}{RMS_B}| < \epsilon$

   where RMS_B = the smallest computed root mean square (RMS), RMS_P = the predicted RMS, and ϵ is a given tolerance (.0001)

2. Maximum allowable iterations (15) were performed

3. Maximum number of consecutive divergent (3) iterations were performed

4. If the RMS for iteration i is less than or equal the minimum allowable $RMS(.3-10^5)$

5.12.1 CONVERG

In this section, we describe the CONVERG card, which is part of DCOPT subdeck and used to set the DC iteration control.

Columns	Format		Description/Contents
1-8	A8		CONVERG
9-11	I3		Maximum number of iterations allowed (default = 15)
12-14	I3		Maximum number of consecutive divergent iterations allowed (default = 3)
15-17	I3		How to process DC if condition number of normal matrix is larger than tolerance
		0	(default) Continue DC, do not compute eigenpair of normal matrix
		1	Continue DC, compute eigenpair of normal matrix
		2	Stop DC if at least one eigenvalue less than .5D-16, compute eigenpair of normal matrix
18-38	G21.14		Iteration convergence tolerance (default = 1.D-4)
39-59	G21.14		Minimum RMS (default = 3.D-6)
60-80	G21.14		Tolerance for condition number of normal matrix (default = .1)

5.13 Output Reports

At the beginning of a DC Program run the Initial Conditions Report is always printed. By default the iteration reports will also be printed after each iteration. These reports include the Observation Residuals (O-C's) Report, the End-of-Iteration Elements Report. The Solve-For Parameter Report, the Variance/Covariance Matrix Report, the End-of-Iteration Summary Report, and the printer-plots of residuals.

The amount of output can be limited by the user, however, via the PRINTOUT keyword card. This keyword card, when included in a DCOPT subdeck, allows the user to print either some or all of the reports involoved. In addition, the O-C report may be printed only every n^{th} iteration if desired.

5.13.1 PRINTOUT

In this section, we describe the PRINTOUT card, part of DCOPT subdeck. This card is used to set Observation Residual Report frequency and plot options.

Columns	Format		Description/Contents
1-8	A8		PRINTOUT
9-11	I3	n	The observation residual report will be generated every n^{th} iteration (default = 1)
12-14	I3		not used
15-17	I3		Print control indicator (see table below)
18-38	G21.14		Desired plot types
39-59	G21.14		not used
60-80	G21.14		not used

Report	Flag = 1	Flag = 2	Flag = 3	Flag = 4	Flag = 5
DC Initial Conditions	All	All	All	All	All
Observation Residual	None	none	F + L	F + L	All
Variance-Covariance Matrix	None	None	None	F + L	All
Current Elements	L	L	F + L	F + L	All
Solve-for Parameter	L	L	F + L	F + L	All
End of Iteration Summary	none	none	F + L	F + L	All
DC Summary	L	L	L	L	L
Orbital Elements	L	L	L	L	L

Note that F means first iteration and L means last iteration.

5.14 ORBIT, ORB1, and EPHEM Files

Satellite ephermeris files in the ORBIT, ORB1, and EPHEM formats can be generated in the DC Program for subsequent use by R&D GTDS or other systems which need a satellite ephemerides. The file generation option can only be used when the Cowell or time-regularized Cowell intergrator is used. The option is invoked through the OUTOPT keyword card in the OGOPT subdeck. The orbit represented on the file will be the orbit used during the last DC Program iteration.

Chapter 6

Examples

In this chapter we give several examples of running the code, using a variety of propagators for various orbit classes. In each case, we give the setup data to prepare a so-called "truth" for the differential corrections, then the input for the various propagators running a differential correction for a certain fit span (one period) and an ephemeris generation for another period past the fit span. These input files were used by Fonte, Neta, Sabol, Danielson and Dyar [5] in their paper on comparison of orbit propagators.

6.1 Decaying Orbit

The first set is for a decaying orbit.

The setup is given by:

```
CONTROL   EPHEM                                            NSSC      9494
EPOCH                820223.0        0.0
ELEMENT1  3  6  1    6635.0814       0.010201164      64.9567
ELEMENT2             228.6393        271.2229         88.164558
OUTPUT    1  2  1    820224.0        0.0              43200.0
ORBTYPE   5  1  1    43200.0         1.0
OGOPT
SPSHPER   3
DRAG      1          1
ATMOSDEN        1
SCPARAM              1.D-6           100.D0
MAXDEGEQ  1          4.0
```

```
MAXORDEQ  1         4.0
POTFIELD  1  6
END
FIN
CONTROL   EPHEM                         OUTPUT                  NSSC       9494
OUTPUT    1  2  1   820226.0            0.0                  21600
ORBTYPE   2  1  1   60.0
OGOPT
DRAG      1         1
ATMOSDEN        1
SCPARAM             1.D-6               100.D0
POTFIELD  1  6
MAXDEGEQ  1         21.0
MAXORDEQ  1         21.0
OUTOPT    1         820224000000.0      820226000000.0       450.0
END
FIN
```

Notes: The program creates an ephemeris for one day starting with 23 February 1982 using semianalytic satellite theory and then using Cowell to propagate for two more days. The first is just to get osculating elements.

Now we list the input for the Brouwer-Lydanne (BL) propagator used in R&D GTDS.

```
CONTROL   DC                                                 NSSC          9494
EPOCH               820224.0            0.0
ELEMENT1  2  4  1   6628.45             0.008921             64.8
ELEMENT2            224.5               271.8                115.25
OBSINPUT 15         820224000000.0      820224013000.0
ORBTYPE   4  0  1
DMOPT
OBSDEV   21 22 23   100.                100.                 100.
OBSDEV   24 25 26   10.                 10.                  10.
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1   1.D-2
END
```

```
OGOPT
POTFIELD  1  6
STATEPAR  4                              1
STATETAB  1  2  3  5.0                   6.0                 19.0
NPQPAR    2  2  0  840224000000.0        0.0                 840224000000.0
NPQPAR    2  3  0  840224000000.0        0.0                 840224000000.0
END
FIN
CONTROL   EPHEM                           OUTPUT              NSSC          9494
OUTPUT    1  2  1  820226.               0.0                 21600
ORBTYPE   4  0  1
OGOPT
POTFIELD  1  6
DRAGPAR   0
OUTOPT   21        820224013000.0        820224030000.0      450.0
END
FIN
```

Notes: This is with NPQPAR cards for drag solve-for parameter.

```
CONTROL   DC                                                  NSSC          9494
EPOCH              820224.0              0.0
ELEMENT1  1  2  1  6628.45               0.008921            64.8
ELEMENT2           224.5                 271.8               115.25
OBSINPUT 15        820224000000.0        820224013000.0
ORBTYPE   2  1  1  60.
DMOPT
OBSDEV   21 22 23  100.                  100.                100.
OBSDEV   24 25 26  10.                   10.                 10.
END
DCOPT
PRINTOUT  1     4
CONVERG   8     1  1.D-4
END
OGOPT
DRAG      1        1
ATMOSDEN        1
```

```
SCPARAM              1.D-6             100.D0
POTFIELD  1  6
MAXDEGEQ  1          4.
MAXORDEQ  1          4.
STATEPAR  1
STATETAB  1  2  3    4.0               5.0              6.0
DRAGPAR   3  1       0.
END
FIN
CONTROL   EPHEM                        OUTPUT           NSSC         9494
OUTPUT    1  2  1    820226.0          0.0              21600
ORBTYPE   2  1  1    60.
OGOPT
DRAG      1          1
DRAGPAR   0
ATMOSDEN        1
SCPARAM              1.D-6             100.D0
POTFIELD  1  6
MAXDEGEQ  1          4.
MAXORDEQ  1          4.
OUTOPT   21          820224013000.0    820224030000.0   450.0
END
FIN
```

Notes: One can run this Cowell with up to 50 by 50 geopotential (4 by 4 is given here). This is not solving for drag. To change that, replace the DRAGPAR card in the DC run to have 1 in the first integer field and leave the rest blank.

```
CONTROL   DC                                            NSSC         9494
EPOCH                820224.0          0.0
ELEMENT1  8 11  1    6628.45           0.008921         64.8
ELEMENT2             224.5             271.8            115.25
ELEMENT3             0                 0                0.001
OBSINPUT 15          820224000000.0    820224013000.0
ORBTYPE  14  1  8    1.
DMOPT
OBSDEV   21 22 23    100.              100.             100.
```

```
OBSDEV    24 25 26  10.                   10.                 10.
END
DCOPT
PRINTOUT  1     4
CONVERG   8     1   1.D-4
END
OGOPT
DRAGPAR   6
POTFIELD  1  7
STATEPAR  3
STATETAB  1  2  3   4.0                   5.0                 6.0
END
FIN
CONTROL   EPHEM                            OUTPUT              NSSC        9494
OUTPUT    1  2  1   820226.0              0.0                 21600
ORBTYPE   14 1  8   1.
OGOPT
DRAGPAR   0
POTFIELD  1  7
OUTOPT    21        820224013000.0        820224030000.0      450.0
END
FIN
```

Notes: In this run of SGP4 one solves for drag.

```
CONTROL   DC                                                  NSSC        9494
EPOCH               820224.0              0.0
ELEMENT1  1  6  1   6628.45               0.008921            64.8
ELEMENT2            224.5                 271.8               115.25
OBSINPUT 15         820224000000.0        820224013000.0
ORBTYPE   5  1  1   43200.0               1.0
DMOPT
OBSDEV    21 22 23  100.                  100.                100.
OBSDEV    24 25 26  10.                   10.                 10.
END
DCOPT
PRINTOUT  1     4
```

```
CONVERG   30        1   1.D-4
END
OGOPT
DRAG       1            1.0
ATMOSDEN            1
SCPARAM                 1.D-6                100.D0
SPGRVFRC   1   1    1   3.0                  1.0                 3.0
SPTESSLC   6   6
POTFIELD   1   6
MAXDEGEQ   1            8.
MAXORDEQ   1            8.
NCBODY     1
STATEPAR   3
STATETAB   1   2    3   4.0                  5.0                 6.0
DRAGPAR    1
DRAGPAR2   1   1
SSTESTFL   1   2    0   0.0
SSTAPGFL   1   0    0   1.0                  0.0                 0.0
END
FIN
CONTROL    EPHEM                              OUTPUT              NSSC            9494
OUTPUT     1   2    1   820226.              000000.0            21600
ORBTYPE    5   1    1   43200.0              1.0
OGOPT
DRAGPAR    0
DRAG       1            1.0
ATMOSDEN            1
SCPARAM                 1.D-6                100.D0
SPGRVFRC   1   1    1   3.0                  1.0                 3.0
SPTESSLC   6   6
POTFIELD   1   6
MAXDEGEQ   1            8.
MAXORDEQ   1            8.
NCBODY     1
OUTOPT    21            820224000000.0       820224030000.0      450.0
END
FIN
```

Notes: This is an optimized DSST run with an 8 by 8 geopotential.

6.2 Low Altitude Circular Orbit

We now turn to an example of low altitude circular orbit such as the orbit of the Hubble Space Telescope.

```
CONTROL   EPHEM                                                 HST        20771
EPOCH                941204.0            211059.5456
ELEMENT1  8 18  1    14.90748717         0.0006208             28.4700
ELEMENT2             219.4160             75.0933              285.0339
ELEMENT3             0.00000000          0.000000              0.000052
OUTPUT    1  2  1    941214.0            211100.0              86400.0
ORBTYPE  14  1  8    1.0
OGOPT
POTFIELD  1  7
OUTOPT    1          941204211100.0      941214211100.0        450.0
END
FIN
```

Notes: Run the above (SGP4) to create an ORB1 file for the ten days starting 4 December 1994, 2111 hours and then run the following differential correction on this data to create the 'truth'. This of course gives an advantage to SGP4 when comparing to other propagators. See discussion in Fonte et al.

```
CONTROL   DC                                                    HST        20771
EPOCH                941204.0            211059.5456
ELEMENT1  1  2  1    6980.0528           0.00171774             28.3267
ELEMENT2             218.4816            40.7065               319.8288
OBSINPUT 15          941204211100.0      941214211100.0
ORBTYPE   2  1  1    60.0
DMOPT
OBSDEV   21 22 23    500.0               500.0                 500.0
OBSDEV   24 25 26    50.0                50.0                  50.0
END
DCOPT
```

```
PRINTOUT  1     4
CONVERG  30     1  1.D-3
END
OGOPT
DRAG      1        1.0
ATMOSDEN        1
SOLRAD    1        1.0
SCPARAM            1.D-6              100.D0
POTFIELD  1  6
MAXDEGEQ  1        21.0
MAXORDEQ  1        21.0
STATEPAR  1
STATETAB  1  2  3  4.0                5.0                 6.0
SOLRDPAR  1
DRAGPAR   1
END
FIN
CONTROL   EPHEM                        OUTPUT              HST             20771
OUTPUT    1  2  1  941204.0           211100.0            86400.0
ORBTYPE   2  1  1  60.0
OGOPT
DRAG      1        1.0
ATMOSDEN        1
SOLRAD    1        1.0
SCPARAM            1.D-6              100.D0
SOLRDPAR  0
DRAGPAR   0
POTFIELD  1  6
MAXDEGEQ  1        21.0
MAXORDEQ  1        21.0
OUTOPT   21        941204211100.0     941214211100.0      400.0
END
FIN
```

Now we bring the input decks used to run BL, Cowell, SGP, SGP4 and optimized DSST.
BL:

```
CONTROL    DC                                             HST       20771
EPOCH                 941204.0           211059.5456
ELEMENT1  2  4  1     6977.90            0.0006208        28.4700
ELEMENT2              219.4160            75.0933         285.0339
OBSINPUT 15           941204211100.0     941204225100.0
ORBTYPE   4  0  1
DMOPT
OBSDEV   21 22 23     100.0              100.0            100.0
OBSDEV   24 25 26     10.0               10.0             10.0
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1     1.D-2
END
OGOPT
POTFIELD  1  6
STATEPAR  4
STATETAB  1  2  3     5.0                6.0              19.0
NPQPAR    2  2  0     941204211059.5456  0.0              941204211059.5456
NPQPAR    2  3  0     941204211059.5456  0.0              941204211059.5456
END
FIN
CONTROL    EPHEM                          OUTPUT          HST       20771
OUTPUT    1  2  1     941204.0           211100.0         86400.0
ORBTYPE   4  0  1
OGOPT
POTFIELD  1  6
DRAGPAR   0
OUTOPT   21           941204225100.0     941205003100.0   400.0
END
FIN
```

Cowell:

```
CONTROL    DC                                             HST       20771
EPOCH                 941204.0           211059.5456
ELEMENT1  1  2  1     6977.90            0.0006208        28.4700
```

```
ELEMENT2              219.4160             75.0933           285.0339
OBSINPUT 15           941204211100.0      941204225100.0
ORBTYPE   2  1  1     60.0
DMOPT
OBSDEV    21 22 23    100.0               100.0             100.0
OBSDEV    24 25 26    10.0                10.0              10.0
END
DCOPT
PRINTOUT  1     4
CONVERG   30    1     1.D-3
END
OGOPT
DRAG      1           1.0
ATMOSDEN        1
SCPARAM               1.D-6               100.D0
SOLRAD    1           1.0
POTFIELD  1  6
MAXDEGEQ  1           4.0
MAXORDEQ  1           4.0
STATEPAR  1
STATETAB  1  2  3     4.0                 5.0               6.0
DRAGPAR   1
SOLRDPAR  1
END
FIN
CONTROL   EPHEM                            OUTPUT            HST           20771
OUTPUT    1  2  1     941204.0            211100.0          86400.0
ORBTYPE   2  1  1     60.0
OGOPT
DRAG      1           1.0
ATMOSDEN        1
SCPARAM               1.D-6               100.D0
SOLRAD    1           1.0
DRAGPAR   0
SOLRDPAR  0
POTFIELD  1  6
MAXDEGEQ  1           4.0
```

```
MAXORDEQ  1        4.0
OUTOPT   21        941204225100.0      941205003100.0      400.0
END
FIN
```

SGP:

```
CONTROL   DC                                               HST          20771
EPOCH              941204.0            211059.5456
ELEMENT1  8 18  1  14.90748717         0.0006208           28.4700
ELEMENT2           219.4160             75.0933            285.0339
ELEMENT3           0.00000674          0.000000            0.000052
OBSINPUT 15        941204211100.0      941204225100.0
ORBTYPE  13  1  8  1.0
DMOPT
OBSDEV   21 22 23  100.0               100.0               100.0
OBSDEV   24 25 26  10.0                10.0                10.0
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1  1.D-3
END
OGOPT
POTFIELD  1  7
STATEPAR  3
STATETAB  1  2  3  4.0                 5.0                 6.0
DRAGPAR   6
END
FIN
CONTROL   EPHEM                         OUTPUT             HST          20771
OUTPUT    1  2  1  941204.0            211100.0            86400.0
ORBTYPE  13  1  8  1.0
OGOPT
POTFIELD  1  7
DRAGPAR   0
OUTOPT   21        941204225100.0      941205003100.0      400.0
END
FIN
```

SGP4:

```
CONTROL   DC                                                HST          20771
EPOCH                  941204.0            211059.5456
ELEMENT1  8 18   1     14.90748717         0.0006208           28.4700
ELEMENT2               219.4160             75.0933            285.0339
ELEMENT3               0.00000000          0.000000            0.000052
OBSINPUT 15            941204211100.0      941204225100.0
ORBTYPE  14   1   8    1.0
DMOPT
OBSDEV   21 22 23      100.0               100.0               100.0
OBSDEV   24 25 26      10.0                10.0                10.0
END
DCOPT
PRINTOUT  1       4
CONVERG  30       1    1.D-3
END
OGOPT
POTFIELD  1   7
STATEPAR  3
STATETAB  1   2   3    4.0                 5.0                 6.0
DRAGPAR   6
END
FIN
CONTROL   EPHEM                             OUTPUT              HST          20771
OUTPUT    1   2   1    941204.0            211100.0            86400.0
ORBTYPE  14   1   8    1.0
OGOPT
POTFIELD  1   7
DRAGPAR   0
OUTOPT   21            941204225100.0      941205003100.0      400.0
END
FIN
```

optimized DSST:

```
CONTROL   DC                                                HST
EPOCH                  941204.0            211059.5456
```

```
ELEMENT1  1  6  1  6977.90            0.0006208         28.4700
ELEMENT2           219.4160            75.0933          285.0339
OBSINPUT 15        941204211100.0     941204225100.0
ORBTYPE   5  1  1  43200.0            1.0
DMOPT
OBSDEV   21 22 23  100.               100.              100.
OBSDEV   24 25 26  10.                10.               10.
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1  1.D-4
END
OGOPT
DRAG      1        1.0
ATMOSDEN        1
SPDRAG    0
SCPARAM            1.D-6              100.D0
SPGRVFRC  1  1  3  3.0                3.0               3.0
SPZONALS  8  2 11
SPMDAILY  8  8  2
POTFIELD  1  6
MAXDEGEQ  1        8.
MAXORDEQ  1        8.
STATEPAR  3
STATETAB  1  2  3  4.0                5.0               6.0
DRAGPAR   1
DRAGPAR2  1  1
SSTESTFL  1  2  0  0.0
SSTAPGFL  1  0  0  1.0                0.0               0.0
END
FIN
CONTROL   EPHEM                        OUTPUT            HST
OUTPUT    1  2  1  941204.0           211100.0          86400.0
ORBTYPE   5  1  1  43200.0            1.0
OGOPT
DRAGPAR   0
DRAG      1        1.0
```

```
ATMOSDEN        1
SPDRAG    0
SCPARAM             1.D-6               100.D0
SPGRVFRC  1  1  3   3.0                 3.0                 3.0
SPZONALS  8  2 11
SPMDAILY  8  8  2
POTFIELD  1  6
MAXDEGEQ  1         8.
MAXORDEQ  1         8.
OUTOPT   21         941204225100.0      941205003100.0      400.0
END
FIN
CONTROL   COMPARE
COMPOPT
CMPEPHEM  1102102 941204225100.0        941205003100.0       6.66666666666
CMPPLOT   1
END
FIN
```

Notes:

1. "Observations" are Mean of 1950 (OBSINPUT)
2. DSST step size is half a day (ORBTYPE)
3. Position "observation" standard deviation is 100 m (OBSDEV)
4. Velocity "observation" standard deviation is 10 cm/s (OBSDEV)
5. Jacchia-Roberts atmospheric density model in AOG (SPDRAG shuts of drag short periodics)
6. 8x8 GEM10 geopotential model in AOG
7. Zonal and m-daily geopotential short periodics only ("1's" on SPGRVFRC card)
8. Truncated zonal short periodics (SPZONALS)
9. Truncated m-daily short periodics (SPMDAILY)

10. Lunar solar point massthird body effects in AOG (absence of NCBODY card, SPGRVFRC)

11. Mean equinoctial solve-fors (STATEPAR)

12. Solving for coefficient of drag, drag partial derivatives (DRAGPAR, DRAGPAR2, SSTESTFL, SSTAPGFL)

13. No drag partial derivatives in subsequent ephemeris generation (DRAGPAR)

14. ORB1 output every 400.0 seconds

6.3 High Altitude Circular Orbit

Now comes the same for high altitude circular orbit such as the TOPEX. The first two decks are used to create the 'truth' in a similar fashion to the low altitude circular orbit.

```
CONTROL   EPHEM                                               TOPEX       20771
EPOCH                  941204.0           113001.5434
ELEMENT1  8 18  1      12.80939311        0.0007391          66.0424
ELEMENT2               297.2917           268.5930            91.4239
ELEMENT3               0.00000000         0.000000           0.000100
OUTPUT    1  2  1      941214.0           113002.0           86400.0
ORBTYPE  14  1  8      1.0
OGOPT
POTFIELD  1  7
OUTOPT    1            941204113002.0     941214113002.0     450.0
END
FIN


CONTROL   DC                                                  TOPEX       20771
EPOCH                  941204.0           113001.5434
ELEMENT1  1  2  1      7721.55            0.0004962          65.8
ELEMENT2               296.8              17.1               342.77
OBSINPUT 15            941204113002.0     941214113002.0
```

```
ORBTYPE   2  1  1  60.0
DMOPT
OBSDEV   21 22 23  500.0           500.0           500.0
OBSDEV   24 25 26  50.0            50.0            50.0
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1  1.D-3
END
OGOPT
DRAG      1        1.0
ATMOSDEN        1
SOLRAD    1        1.0
SCPARAM            1.D-6           100.D0
POTFIELD  1  6
MAXDEGEQ  1        21.0
MAXORDEQ  1        21.0
STATEPAR  1
STATETAB  1  2  3  4.0             5.0             6.0
SOLRDPAR  1
DRAGPAR   1
END
FIN
CONTROL   EPHEM                     OUTPUT          TOPEX           20771
OUTPUT    1  2  1  941204.0        152002.0        86400.0
ORBTYPE   2  1  1  60.0
OGOPT
DRAG      1        1.0
ATMOSDEN        1
SOLRAD    1        1.0
SCPARAM            1.D-6           100.D0
SOLRDPAR  0
DRAGPAR   0
POTFIELD  1  6
MAXDEGEQ  1        21.0
MAXORDEQ  1        21.0
OUTOPT   21        941204113002.0  941204152002.0  460.0
```

```
END
FIN
```

Now comes the runs for BL, Cowell, SGP, SGP4 and the optimized DSST.

BL:

```
CONTROL   DC                                                TOPEX       20771
EPOCH                941204.0            113001.5434
ELEMENT1  2  4  1    7714.39             0.0007391          66.0424
ELEMENT2             297.2917            268.5930           91.4239
OBSINPUT 15          941204113002.0      941204132502.0
ORBTYPE   4  0  1
DMOPT
OBSDEV   21 22 23    100.0               100.0              100.0
OBSDEV   24 25 26    10.0                10.0               10.0
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1    1.D-2
END
OGOPT
POTFIELD  1  6
STATEPAR  4
STATETAB  1  2  3    5.0                 6.0                19.0
NPQPAR    2  2  0    941204113001.5434   0.0                941204113001.5434
NPQPAR    2  3  0    941204113001.5434   0.0                941204113001.5434
END
FIN
CONTROL   EPHEM                           OUTPUT            TOPEX       20771
OUTPUT    1  2  1    941204.0            152002.0           86400.0
ORBTYPE   4  0  1
OGOPT
POTFIELD  1  6
DRAGPAR   0
OUTOPT   21          941204132502.0      941204152002.0     460.0
END
FIN
```

Cowell:

```
CONTROL   DC                                              TOPEX       20771
EPOCH                  941204.0          113001.5434
ELEMENT1  1  2  1      7714.39           0.0007391        66.0424
ELEMENT2               297.2917          268.5930         91.4239
OBSINPUT 15            941204113002.0    941204132502.0
ORBTYPE   2  1  1      60.0
DMOPT
OBSDEV   21 22 23      100.0             100.0            100.0
OBSDEV   24 25 26      10.0              10.0             10.0
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1      1.D-3
END
OGOPT
DRAG      1            1.0
ATMOSDEN        1
SOLRAD    1            1.0
SCPARAM                1.D-6             100.D0
POTFIELD  1  6
MAXDEGEQ  1            4.0
MAXORDEQ  1            4.0
STATEPAR  1
STATETAB  1  2  3      4.0               5.0              6.0
SOLRDPAR  3            -5.4211956
DRAGPAR   3  1         -.0669424
END
FIN
CONTROL   EPHEM                          OUTPUT           TOPEX       20771
OUTPUT    1  2  1      941204.0          152002.0         86400.0
ORBTYPE   2  1  1      60.0
OGOPT
DRAG      1            1.0
ATMOSDEN        1
SOLRAD    1            1.0
SCPARAM                1.D-6             100.D0
```

```
SOLRDPAR  3          -5.4211956
DRAGPAR   3   1      -.0669424
POTFIELD  1   6
MAXDEGEQ  1          4.0
MAXORDEQ  1          4.0
OUTOPT    21         941204132502.0      941204152002.0      460.0
END
FIN
```

SGP:

```
CONTROL   DC                                                  TOPEX        20771
EPOCH                941204.0            113001.5434
ELEMENT1  8 18  1    12.80939311         0.0007391           66.0424
ELEMENT2             297.2917            268.5930             91.4239
ELEMENT3             0.00000000          0.000000            0.000100
OBSINPUT 15          941204113002.0      941204132502.0
ORBTYPE   13  1  8   1.0
DMOPT
OBSDEV    21 22 23   100.0               100.0               100.0
OBSDEV    24 25 26   10.0                10.0                10.0
END
DCOPT
PRINTOUT  1      4
CONVERG   30     1   1.D-3
END
OGOPT
POTFIELD  1   7
STATEPAR  3
STATETAB  1   2  3   4.0                 5.0                 6.0
DRAGPAR   0
END
FIN
CONTROL   EPHEM                           OUTPUT              TOPEX        20771
OUTPUT    1   2  1   941204.0            152002.0            86400.0
ORBTYPE   13  1  8   1.0
OGOPT
```

```
POTFIELD  1  7
DRAGPAR   0
OUTOPT   21         941204132502.0      941204152002.0      460.0
END
FIN
```

SGP4:

```
CONTROL   DC                                                 TOPEX        20771
EPOCH                941204.0            113001.5434
ELEMENT1  8 18  1   12.80939311         0.0007391           66.0424
ELEMENT2            297.2917            268.5930             91.4239
ELEMENT3            0.00000000          0.000000            0.000100
OBSINPUT 15         941204113002.0      941204132502.0
ORBTYPE  14  1  8   1.0
DMOPT
OBSDEV   21 22 23   100.0               100.0               100.0
OBSDEV   24 25 26   10.0                10.0                10.0
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1   1.D-3
END
OGOPT
POTFIELD  1  7
STATEPAR  3
STATETAB  1  2  3   4.0                 5.0                 6.0
DRAGPAR   0
END
FIN
CONTROL   EPHEM                          OUTPUT              TOPEX        20771
OUTPUT    1  2  1   941204.0            152002.0            86400.0
ORBTYPE  14  1  8   1.0
OGOPT
POTFIELD  1  7
DRAGPAR   0
OUTOPT   21         941204132502.0      941204152002.0      460.0
```

```
END
FIN
```

optimized DSST:

```
CONTROL   DC                                                TOPEX        20771
EPOCH                   941204.0             113001.5434
ELEMENT1  1   6   1     7714.39              0.0007391          66.0424
ELEMENT2                297.2917             268.5930           91.4239
OBSINPUT 15             941204113002.0       941204132502.0
ORBTYPE   5   1   1     43200.0              1.0
DMOPT
OBSDEV   21  22  23     100.                 100.               100.
OBSDEV   24  25  26     10.                  10.                10.
END
DCOPT
PRINTOUT  1       4
CONVERG  30       1     1.D-4
END
OGOPT
SPGRVFRC  1   1   3     3.0                  3.0                3.0
SPZONALS  8   2  11
SPMDAILY  8   8   2
POTFIELD  1   6
MAXDEGEQ  1             8.
MAXORDEQ  1             8.
STATEPAR  3
STATETAB  1   2   3     4.0                  5.0                6.0
SSTESTFL  1   3   0     0.0
SSTAPGFL  1   0   1     0.0                  0.0                0.0
END
FIN
CONTROL   EPHEM                               OUTPUT            EXPLORER     65032A
OUTPUT    1   2   1     941204.0             152002.0           86400.0
ORBTYPE   5   1   1     43200.0              1.0
OGOPT
SPGRVFRC  1   1   3     3.0                  3.0                3.0
```

```
SPZONALS  8  2 11
SPMDAILY  8  8  2
POTFIELD  1  6
MAXDEGEQ  1        8.
MAXORDEQ  1        8.
OUTOPT   21        941204132502.0      941204152002.0      460.0
END
FIN
```

6.4 Molniya Orbit

We finish the set by giving an example of Molniya orbit. Here we only give Cowell, SGP4 and the optimized DSST after the two decks creating the 'truth'.

```
CONTROL   EPHEM                                              NSSC        92011A
EPOCH              940829.0           062523.8964
ELEMENT1  8 18  1  2.00624730         0.7310151             63.7771
ELEMENT2           48.3761            289.1885              9.5679
ELEMENT3           0.                 0.                    0.001063
OUTPUT    1  2  1  940908.0           062524.0              86400.0
ORBTYPE  14  1  8  1.0
OGOPT
POTFIELD  1  7
OUTOPT    1        940829062524.0     940908062524.0        450.0
END
FIN
```

```
CONTROL   DC                                                NSSC        92011A
EPOCH              940829.0            062523.8964
ELEMENT1  1  2  1  26573.92            0.7313                64.0
ELEMENT2           47.9                289.1                 9.52
OBSINPUT 15        940829062524.0      940903062524.0
ORBTYPE   2  1  1  60.
DMOPT
```

```
OBSDEV   21 22 23  500.                500.                500.
OBSDEV   24 25 26  50.                 50.                 50.
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1  1.D-4
END
OGOPT
SOLRAD    1        1.0
SCPARAM            1.D-6               100.D0
DRAG      1        1.0
ATMOSDEN        1
POTFIELD  1  6
MAXDEGEQ  1        21.
MAXORDEQ  1        21.
STATEPAR  1
STATETAB  1  2  3  4.0                 5.0                 6.0
SOLRDPAR  1
DRAGPAR   1
END
FIN
CONTROL   EPHEM                         OUTPUT              NSSC         92011A
OUTPUT    1  2  1  940908.0            062524.0            86400.0
ORBTYPE   2  1  1  60.
OGOPT
SOLRDPAR  0
SOLRAD    1        1.0
SCPARAM            1.D-6               100.D0
DRAGPAR   0
DRAG      1        1.0
ATMOSDEN        1
POTFIELD  1  6
MAXDEGEQ  1        21.
MAXORDEQ  1        21.
OUTOPT   21        940829062524.0   940908062524.0      450.0
END
FIN
```

Cowell:

```
CONTROL   DC                                             MOLNIYA    92011A
EPOCH               940829.0         062523.8964
ELEMENT1  1  2  1   26573.92         0.7310151           63.7771
ELEMENT2            48.3761          289.1885            9.5679
OBSINPUT 15         940829062524.0   940829182524.0
ORBTYPE   2  1  1   60.
DMOPT
OBSDEV   21 22 23   100.             100.                100.
OBSDEV   24 25 26   10.              10.                 10.
END
DCOPT
PRINTOUT  1     4
CONVERG  30     1   1.D-4
END
OGOPT
DRAG      1         1.0
ATMOSDEN        1
SCPARAM             1.D-6            100.D0
SOLRAD    1         1.0
POTFIELD  1  6
MAXDEGEQ  1         4.
MAXORDEQ  1         4.
STATEPAR  1
STATETAB  1  2  3   4.0              5.0                 6.0
DRAGPAR   1
SOLRDPAR  1
END
FIN
CONTROL   EPHEM                       OUTPUT             MOLNIYA    92011A
OUTPUT    1  2  1   940830.0         062524.0            21600.
ORBTYPE   2  1  1   60.
OGOPT
DRAG      1         1.0
DRAGPAR   0
ATMOSDEN        1
SCPARAM             1.D-6            100.D0
```

```
SOLRAD     1           1.0
SOLRDPAR   0
POTFIELD   1   6
MAXDEGEQ   1           4.
MAXORDEQ   1           4.
OUTOPT    21           940829182524.0     940830062524.0      450.0
END
FIN
```

SGP4:

```
CONTROL    DC                                                  MOLNIYA     92011A
EPOCH                  940829.0           062523.8964
ELEMENT1   8  18   1   2.0062473          0.7310151            63.7771
ELEMENT2               48.3761            289.1885             9.5679
ELEMENT3               0                  0                    0.001063
OBSINPUT  15           940829062524.0     940829182524.0
ORBTYPE   14   1   8   1.0
DMOPT
OBSDEV    21  22  23   100.               100.                100.
OBSDEV    24  25  26   10.                10.                 10.
END
DCOPT
PRINTOUT   1       4
CONVERG   30       1   1.D-4
END
OGOPT
DRAGPAR    6
POTFIELD   1   7
STATEPAR   3
STATETAB   1   2   3   4.0                5.0                 6.0
END
FIN
CONTROL    EPHEM                          OUTPUT               MOLNIYA     92011A
OUTPUT     1   2   1   940830.0           062524.0            21600.
ORBTYPE   14   1   8   1.0
OGOPT
DRAGPAR    0
```

```
POTFIELD  1  7
OUTOPT   21        940829182524.0      940830062524.0       450.0
END
FIN
```

optimized DSST:

```
CONTROL   DATAMGT                                            NSSC        92011A
OGOPT
POTFIELD  1  6
END
FIN
CONTROL   DC                                                 NSSC        92011A
EPOCH                940829.0            062523.8964
ELEMENT1  1  6  1    26586.73            0.7315              64.0
ELEMENT2             47.8                289.1               9.51
OBSINPUT 15          940829062524.0      940829182524.0
ORBTYPE   5  1  1    43200.0             1.0
DMOPT
OBSDEV   21 22 23    100.                100.               100.
OBSDEV   24 25 26    10.                 10.                10.
END
OGOPT
SPLUNARA  4  3  7    2.0
SPSOLARA  2  2  4    2.0
DRAG      1          1.0
ATMOSDEN        1
SPDRAG    0
SCPARAM              1.D-6               100.D0
SOLRAD    1          1.0
SPSRP     1
SPGRVFRC  1  1  3    1.                  1.                 3.
SPMDAILY  4  4  2
SPZONALS  6  5 10
MAXDEGEQ  1          8.
MAXORDEQ  1          8.
STATEPAR  3
STATETAB  1  2  3    4.0                 5.0                6.0
```

```
DRAGPAR    1
DRAGPAR2   1  1
SOLRDPAR   1
SSTESTFL   1  2  0  0.0
SSTAPGFL   1  0  0  1.0                0.0                 1.0
END
DCOPT
PRINTOUT   1     4
CONVERG   30     1  1.D-3
END
FIN
CONTROL    EPHEM                       OUTPUT              NSSC         92011A
OUTPUT     1  2  1  940830.0           062524.0            21600.
ORBTYPE    5  1  1  43200.0            1.0
OGOPT
SPLUNARA   4  3  7  2.0
SPSOLARA   2  2  4  2.0
DRAG       1        1.0
DRAGPAR    0
ATMOSDEN         1
SPDRAG     0
SCPARAM             1.D-6              100.D0
SOLRAD     1        1.0
SOLRDPAR   0
SPSRP      1
SPGRVFRC   1  1  3  1.                 1.                  3.
SPMDAILY   4  4  2
SPZONALS   6  5 10
MAXDEGEQ   1        8.
MAXORDEQ   1        8.
OUTOPT    21        940829182524.0   940830062524.0      450.0
END
FIN
CONTROL    COMPARE                                          MOLNIYA     92011A
COMPOPT
CMPEPHEM   1102102  940829182524.0   940830062524.0      7.5
CMPPLOT    1                                             2.0
```

```
END
FIN
```

Chapter 7

References

1. Danielson, D. A., Sagovac, C. P., Neta, B., Early, L. W., Semianalytic Satellite Theory (SST): Mathematical Algorithms, Naval Postgraduate School Technical Report NPS-MA-95-002, Department of Mathematics, Monterey, CA 93943, 1995.

2. L. Early, A package of linkage diagrams for portions of GTDS, CSDL memo dated 27 January 1994.

3. Computer Science Corporation and System Development and Analysis Branch (GSFC), Research and Development Goddard Trajectory Determination System (R&D GTDS) User's Guide, July 1978.

4. Goddard Space Flight Center Report X-582-76-77, Mathematical Theory of the Goddard Trajectory Determination System, Cappellari, J.O, Veleg, C.E., Veliz, C.E. and Fuchs, A.J. (eds), April 1976.

5. D. J. Fonte, B. Neta, C. Sabol, D. A. Danielson and W. R. Dyar, Comparison of Orbit Propagators in the Research and Development Goddard Trajectory Determination System (R & D GTDS). Part I: Simulated Data, Proceeding AAS/AIAA Astrodynamics Conference, Halifax, Nova Scotia, August 14-17, 1995.

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